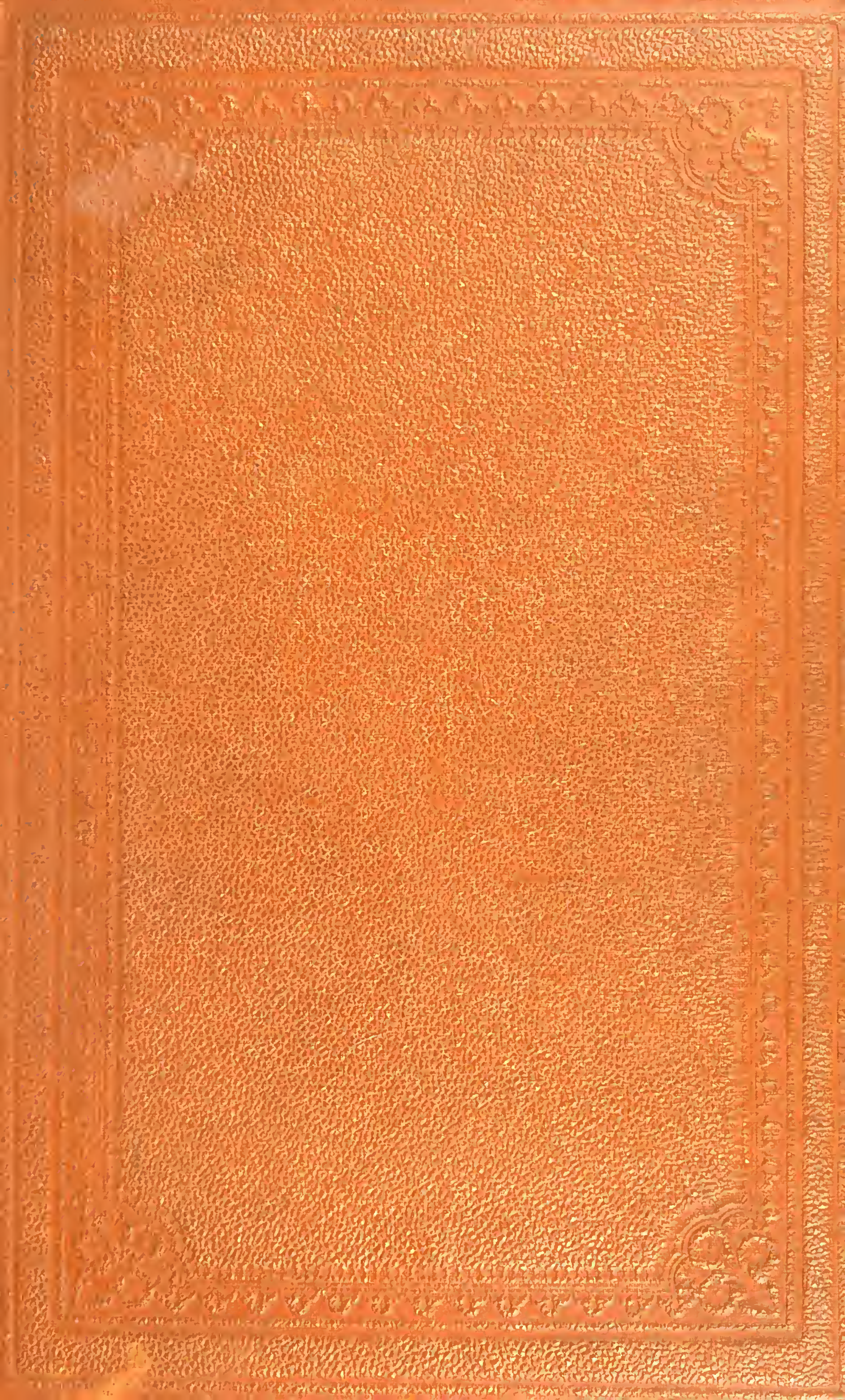

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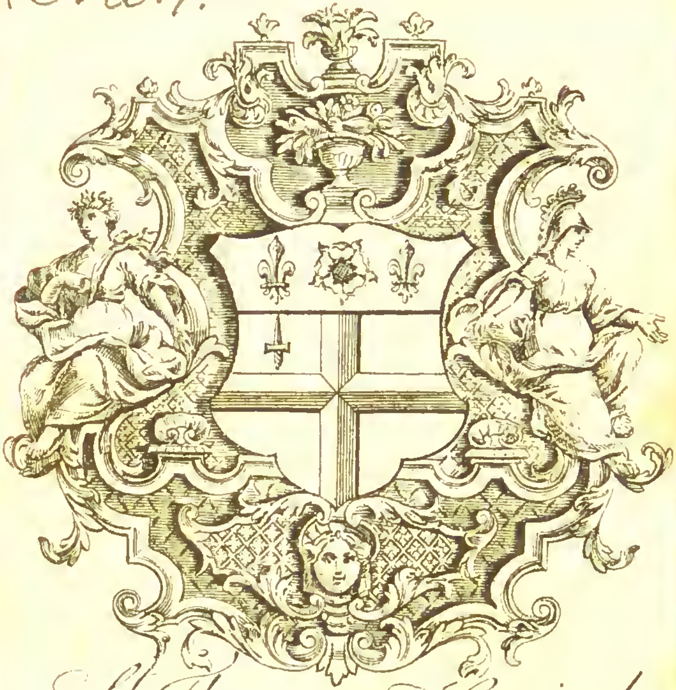

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ELEMENTS

OF

PHYSICS,

OR

NATURAL PHILOSOPHY.

Written for General Uſe,

IN NON-TECHNICAL LANGUAGE.

By NEIL ARNOTT, M.D., F.R.S.,
OF THE ROYAL COLLEGE OF PHYSICIANS; PHYSICIAN EXTRAORDINARY TO THE QUEEN; MEMBER OF THE SENATE OF THE UNIVERSITY OF LONDON;
ETC. ETC.

SIXTH AND COMPLETED EDITION.

PART II.

LONDON: LONGMANS, GREEN, & Co.
1865.

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LONDON : PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET
AND CHARING CROSS.

ELEMENTS

OF

NATURAL PHILOSOPHY.

PART IV.

DOCTRINES OF IMPONDERABLE SUBSTANCE, UNDER THE HEADS OF HEAT, LIGHT, ELECTRICITY, AND MAGNETISM.

834. To minds entering on this study, it may facilitate the conception of a substance which is without weight, or at least is at present imponderable by human art, to consider again the nature of *air*, as explained in Articles 511 and 512. Until lately, men were so imperfectly acquainted with the constitution of the universe around them, that a person placed in an apartment which offered to view nothing but the naked walls, would have said that it was empty, meaning literally what he said; and even when advertised that there was *air* in the room, he would still have been far from possessing a clear notion that it was full of aërial fluid driven in and compressed by the weight of the atmosphere above, just as an open vessel at the bottom of the sea is full of water under pressure of the water above, and that if no air were allowed to escape from the room, even so small a body as an apple could not be thrust into it additionally but by a force of many pounds; that is to say, but by a force somewhat greater than the atmospheric pressure of about 15 lbs. per square inch of surface, which is really seeking entrance into all places at the surface of the earth, and is resisted only by the bulk of the elastic air already in the places. This truth, however, is now clearly understood, and is strikingly and familiarly illustrated by the recent adoption of the substance of air in place of feathers, as stuffing for beds and pillows.

A bag or sack suspended by its lip in the air, and held quite open by a hoop near its mouth, in common language is called empty, but if air-tight, and it be then firmly closed above the hoop, it imprisons its fill of air, just as a bag similarly managed under water imprisons its fill of water. Although air so confined is more moveable within the bag than feathers, its entire mass is much less compressible. Now common air, at the surface of the earth, when weighed by suitable means, is found in a cubic foot to contain nearly an ounce and a third of ponderable substance, and may, by causing it to combine chemically with other substances, be reduced to very small bulk, either with the form of a liquid or of a solid; proving how small a quantity of ponderable matter under certain circumstances can occupy great space. Then common air is by no means the lightest known substance, which as powerfully resists the intrusion of other bodies where it exists. Hydrogen gas, for instance, of the same space-occupying force, weighs only a fourteenth part as much, and therefore a few ounces of it confined in a strong sack as broad as the foundation of a house, would, if the atmospheric pressure above were kept off, support a house, or a vessel as large as a house, filled with water to a height of thirty feet, without having its bulk diminished, the gas itself being then eighty thousand times lighter than its bulk of gold; and if the pressure be taken off from such gas at the surface of the earth, it readily expands to a volume even a thousand times as great, still exerting a considerable outward elasticity.

The mind, pursuing the idea of such expansion or occupancy of space by a small quantity of ponderable matter, is prepared to admit the possibility of there being a fluid medium throughout space, which, although it might press, resist, communicate motion, and have other influences in common with more ponderable matter, might have neither weight nor inertia discoverable by means at present known. While we are contemplating, then, or modifying the agencies concerned in the phenomena of heat and cold, of light and darkness, of electricity in its forms of thunder and lightning, of galvanism, or of magnetism, in a word, the most striking phenomena of nature, we may be dealing with matter having the subtile constitution now spoken of. And as in the terrestrial atmosphere there are various kinds of air present, as those called oxygen and nitrogen, of distinct nature, so in a more subtile medium filling space, there may be various ingredients.

835. Philosophers now incline to the opinion that there is at least one such subtile fluid or medium occupying the wide space of the universe, and tending to equable diffusion, which fluid pervades denser substances somewhat as water pervades a sponge or loose sand, having peculiar relations to each chemical element. They believe farther that the kinds of phenomena above referred to, exhibiting sometimes the highest beauty, sometimes awful intensity and power, are dependent more or less on the motions or other affections of such fluid or fluids, somewhat as the sensation of *sound* in all its varieties is produced in the delicate structure of the ear by modifications of motion in the air. Many philosophers until lately held the causes both of light and of heat, to be subtile particles projected through space, somewhat as sand might be scattered by an explosion, such peculiar particles being present only when the effects were perceived; but now they hold the phenomena to be connected with vibratory motions in such a subtle elastic medium as above described, and for heat moreover in the known ponderable matter of the bodies in which the heat exists.

We mention these hypotheses, not with the view of entering upon a detailed examination of their respective merits, or of asserting that any one of them is the whole explanation, but merely to make the reader aware of the directions which inquirers' minds have taken in pursuing the investigation. The ascertained facts and laws of change important to be known to the general student can be described independently of such hypotheses.

836. Successive steps by which men have approached their present knowledge of the nature of heat have been nearly as follows:—

1st. Of old it was thought that sound was a subtile something which shot and spread around from sounding bodies and entered the ears of persons within a certain distance, producing the sensation called sound. It was then observed that bodies whilst sounding were generally in a state of visible tremor or vibration, like the lip of a bell or the string of a musical instrument; but until the time of Galileo it was not known that the air surrounding all things on earth is a material elastic fluid, having weight, inertia, and bulk like other kinds of ponderable matter, being capable, therefore, of receiving and conveying to a distance the tremors or minute vibrations of a sounding body, nearly as the surface of a pond into which a pebble is dropped exhibits a succession of circular waves spreading from the spot where the stone falls to considerable distances around. The air might thus act as by a gentle touch on the delicate structure of the internal ear. A proof that such a supposition was well founded was afforded after the invention of the air-pump by striking experiments. A small bell placed within the receiver of an air-pump, and made to ring continuously by the action of a spring, is heard distinctly while there is air in the receiver, but the sound becomes less and less audible in proportion as the air is abstracted, until no air remains, and then no sound is heard; on re-admitting air the sound gradually increases again and at last is as loud as at first. Other facts were soon observed all proving the same truth—that the sound was conveyed by undulation of the air. Thus if two musical strings similarly stretched were placed not far from each other, the sounding vibration produced by a tug at one of them was quickly produced also in the other, through the medium of the undulations of the air between them. And it was found that aërial undulations of sound striking against a smooth flat surface were turned back or reflected from that so as to form what is called an echo, nearly as the waves of water in a pond having upright sides are turned back or reflected by these.

2ndly. It was then suspected that light travelling freely through air, and still more readily through space deemed a vacuum, was an undulatory phenomenon of the same nature as sound, only taking place in a fluid still more subtile than air and which pervaded space even to beyond the sun and stars,—a fluid without weight or inertia, but capable of affecting by its motion the extremely sensitive nerve called the retina, spread as a lining on the interior surface of the eye. As the undulations of water in a pond are reflected from the upright wall, and as the undulations of sound are reflected from smooth surfaces to form an echo, so, nearly, are the undulations of light in the supposed medium reflected from the surface of smooth mirrors. Many other close resemblances were noted between these different kinds of undulation, as will be shown in future pages.

3rdly. Then, because heat radiates from the sun and other luminous bodies as light does, and in apparent union with light, having the same marvellous speed, and being reflected from surfaces exactly like light, so that its rays can be made to converge or diverge by mirrors and transparent lenses as the rays of light do, and thereby to form burning glasses and mirrors, there seemed proof that heat also is of an undulatory nature, produced in the same or in a similar subtile diffused fluid—most probably in the same fluid—according to the marvellous simplicity which pervades nature.

837. The other very important phenomena and effects of heat, such as the dilating, melting, vaporizing, &c., of ponderable substances of which the atoms may take on the undulatory condition, are not yet fully thus explained, but rapid advances are being made in this department of knowledge.

838. Yet further, as will be shown in the chapters on Electricity and Magnetism, the phenomena of these also appear to be forms of motion and action closely allied to those of light and heat; for both light and heat are produced with highest intensity by electrical apparatus. And some inquirers are prepared to learn that even the gravitation and inertia of ponderable matter, no causes of which have yet been plausibly conjectured, will be better understood when the nature of the imponderables is more fully ascertained. Lastly may come from the same source farther explanation of the chemical affinities, of crystallization, &c. Some speculators have gone so far as to suppose that the different gases are merely combinations of the diffused ethereal medium with minute quantities of the different kinds of ponderable substance.

The object of this work, however, is not to deal with deep questions of causation yet unsettled, and which can interest only a small class of readers, but to give such knowledge of important facts and laws as befits the general student. Newton, by discovering the laws of gravitation which regulate the great phenomenon of the universe, singularly elevated the condition of man on earth, but he threw out no conjecture as to the occult cause of gravitation.

PART IV.

CHAPTER I.—ON HEAT.

ANALYSIS OF THE SECTION.

Heat may be strikingly referred to as that which causes the difference between winter and summer, between tropical gardens and polar wastes. It cannot be exhibited apart, nor proved to have weight or inertia, but the change of its amount in bodies is conveniently estimated by the concomitant change of their bulk; any substance so circumstanced as to allow this to be accurately measured serving as a THERMOMETER.

Heat diffuses itself among neighbouring bodies until all have the same temperature, that is, until all similarly affect a thermometer. Its inferior degrees are denoted by the term COLD. *It spreads partly through their structure, or by conduction, as it is called, with a progress, different for different substances, and which in fluids is quickened and modified by the motion of their particles; and it spreads partly also by being radiated or shot like light from one body to another, through transparent media or open space, with readiness influenced by the material and state of the giving and receiving surfaces.*

Heat, by entering bodies, expands them, and through a range which includes, as three successive stages, the forms of SOLID, LIQUID, *and* AIR *or* GAS*; becoming thus in nature the grand antagonist and modifier of that attraction which holds corporeal particles together, and which, if acting alone, would reduce the whole material universe to one solid lifeless mass. Each particular substance, however, according to the nature, proximity, &c., of its ultimate particles, takes a certain quantity of heat (said to mark its capacity), to produce in it a given change of temperature or calorific tension; undergoing expansion then in a degree proper to itself, and changing its form to liquid and air at points of temperature proper to itself. Such expansion in bodies generally increases more rapidly than the temperature, as if the cohesion of their particles lessened with increase of distance; being remarkably greater therefore in liquids than in solids, and in airs than in liquids; and the rate of expansion, moreover, being quickened as the bodies approach their points of changing form to liquid or air. To produce these two changes, a large quantity of heat enters them; but in the new arrangement of particles and generally increased volume of the mass, it becomes hidden from the thermometer, and is therefore called* LATENT HEAT.

For any given substance the changes of form happen so constantly at the same temperature, that they mark fixed points in the general scale of temperature, and enable men to regulate and compare thermometers.—Heat by changing the forms of different substances at different temperatures, influences much their chemical combination.—Heat influences much the functions of vegetable and animal life.

*The great source of heat is the sun; but man has gradually learned, by combustion, electricity, and other means, to command heat at all times, for purposes of highest utility to his race.**

"*Heat may be strikingly referred to as that which causes the difference between summer and winter, between the gardens of the equator and polar wastes.*" (See the Analysis, p. 406.)

839. In the warm and temperate climates of the earth, its surface affords a delightful abode for man and inferior animals, supplying all their wants and desires; but where winter comes with a temperature below the freezing point of water, the scene is entirely changed. Then the earth with its waters is soon bound up in snow and ice, the trees and shrubs become leafless, appearing everywhere like withered skeletons,—countless multitudes of living creatures, owing either to the bitter cold or deficiency of food, are perishing in the snows—nature seems dying or dead. The reverse change takes place when spring returns, that is, when heat returns. The earth is again uncovered and soft, the rivers flow, the lakes are again liquid mirrors, the warm showers come to foster vegetation, which soon covers the ground with beauty and plenty. Man, lately inactive, is recalled to many duties; his water-wheels are everywhere at work, his boats are again on the canals and streams, his busy fleets of industry are along the shores:—winged life in new multitudes fills the sky, finny life similarly fills the waters, and every spot of earth teems with vitality and joy. Many persons regard these changes of season as if they

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* It is to be remarked here, that many phenomena in which heat plays an important part, have been described in preceding chapters of this work;—for instance, the action of the steam-engine, the phenomena of winds, many facts in meteorology, &c., under the head of Pneumatics. In a separate treatise on heat, these could not with propriety have been omitted; but in a comprehensive system of physical science like the present, they find their fit place, where, being surrounded by subjects resembling them in more intricate particulars, they can be more concisely and clearly explained.

came like the successive positions of a turning wheel, of which one necessarily brings the next; not adverting that it is the single circumstance of change of temperature which effects all. But if the colds of winter arrive too early, they unfailingly produce the wintry scene, and if warmth come before its time in spring, it expands the bud and the blossom, which a return of frost will surely destroy. A seed sown in an ice-house never awakens to life.

Again, as regards climates;—the earthy matters forming the exterior of our globe, and therefore entering into the composition of soils, are not different for different latitudes; at the equator, for instance, and near the poles. That the aspect of nature then in these two situations exhibits permanently a contrast more striking still than between the annual summer and winter of one place in a temperate and changing climate, is owing merely to the great inequality of temperature, which is permanent. Where heat abounds, we see the magnificent scene of uninterrupted tropical fertility: the earth everywhere covered with luxuriant vegetation in much greater variety than the milder temperate regions can show, in the midst of which, animal forms are equally abundant, many of the species having surpassing beauty, as birds, for instance, with plumage as brilliant as the gayest flowers. The pure warm air is loaded with perfume from the spice-beds, and happy human inhabitants call the scene a paradise.—Again, where heat is permanently absent, there is the dreary spectacle of polar barrenness, bare rock or mountain, when not covered with snow or ice, instead of fertile fields; no rain, nor cloud, nor dew; vegetable life scarcely existing, and but of lowly form in some sheltered spots facing the sun. In the winter of these climates, during which the sun does not rise above the horizon for nearly six months, the new horrors are added, of the unbroken darkness and dreadful silence, with cold benumbing all life, and even freezing mercury. Into such a scene civilized man may penetrate from more favoured climes, but he can only leave his protecting ship and fires for short periods, nearly as he might issue from a diving-bell at the bottom of the sea. While winter then, or the temporary absence of heat, may be called the sleep of nature, the more permanent torpor about the poles is more like its death. Truly, therefore, may heat, the subject of our present chapter, be considered as the sustainer of life in the universe.

"*Heat cannot be exhibited apart, nor proved to have weight or inertia.*" (Read the Analysis, page 406.)

840. Although heat is known to be abundant in the sunbeam, and to radiate copiously from a blazing fire, we cannot otherwise arrest or detect it in its progress than by allowing it to enter, and remain, in some ponderable substance. We know hot iron or hot water, or hot air, but nature nowhere presents to us, nor has art succeeded in exhibiting to us heat alone.

If we balance a quantity of ice in a delicate weigh-beam, guarded against air-currents, and then leave it to melt, the equilibrium will not be in the slightest degree disturbed. Or if we substitute for the ice, boiling water or red-hot iron, and leave these to cool, there will be no difference in the result. If we place a pound of mercury in one scale of the beam and a pound of water in the other, and then either heat or cool both through the same number of thermometric degrees, although about thirty times more heat (as will be explained below) enters or leaves the bulky water than the dense mercury, the two substances will still remain perfectly equipoised.

Again, a broad sunbeam, with its intense light and heat, may be concentrated by a powerful lens or mirror, and be made to fall upon the scale of a most delicate balance placed in a vacuum, but will produce no depressing effect on the scale, as would follow if what constitutes the beam had the least forward motal inertia or momentum.

841. Such were among the facts which led certain inquirers to reject the old theory of the material or separate existence of a matter of heat called *caloric*, and to hold heat to be merely motion of a certain kind among the material particles of bodies, as sound is motion of another kind among the same particles. The following facts they considered to point to the same conclusion. Heat can be produced without limit by friction, as—when savages light their fires by rubbing together two pieces of wood—when Count Rumford made great quantities of water boil, by causing a blunt borer to rub against a mass of metal immersed in the water—when Sir Humphry Davy quickly melted pieces of ice by rubbing them against each other in a room cooled below the freezing point, &c. These facts, and others, seemed to square well with their assumption, that the

phenomena of heat indicate undulatory forms of motion among ponderable atoms and in an exceedingly subtile fluid or ether pervading the universe.

> "*The change of its quantity in bodies is conveniently estimated by the concomitant change of their bulk, any substance so circumstanced as to allow this to be accurately measured, serving as a thermometer.*"

842. If we heat a wire it is lengthened; if we heat water in a full vessel, a part runs over; if we heat air in a bladder, the bladder is distended: in a word, if we heat any substance, its volume increases in some proportion to the increase of temperature,—and the increase of volume may be measured. The reason why, for measurements of heat generally, a contrivance in which the expansion of mercury can be watched, *viz.* the mercurial thermometer, is commonly preferred to others, will be fully understood only by the mind which has considered farther the general subject; and we touch upon the matter here, only to state that a mercurial thermometer is a small bulb or bottle of glass filled with mercury, and having a long very narrow stalk or neck, in which the mercury rises when expanded by heat, and falls when heat is withdrawn. The stalk between the points at which the mercury stands when the bulb is placed first in freezing and then in boiling water, is divided into a convenient number of parts called degrees, which division appearing on a scale applied to the stalk, is continued similarly above and below these points.

> "*Heat diffuses itself among neighbouring bodies until all have acquired the same temperature; that is to say, until all will similarly affect a thermometer.* (See the Analysis, page 406.)

843. An iron bolt thrust in among burning coals soon becomes red-hot like them. If it be the heater of a tea-urn, it will, when afterwards placed in its receptacle amidst the water, give part of its lately acquired heat to the water, until the water boils. Boiling water, again, soon imparts heat to an egg placed in it. A feverish head yields heat to a bag of cold water or of ice laid upon it.—A hundred objects enclosed in the same apartment, if tested after a time by the thermometer, all indicate the same temperature.

"*The inferior degrees or absence of heat are denoted by the term* COLD."

844. When the hand touches a body of higher temperature than itself, it receives heat according to the law just explained, and it experiences a peculiar sensation called that of warmth; when it touches a body of lower temperature than itself, it gives out heat for a like reason, and experiences another and very different sensation called that of coldness. Now warmth and coldness, considered as existing in the bodies themselves, although thus appearing opposites, mark only degrees of the same object, *temperature,* contrasted by name for convenience, sake, in reference to the ordinary temperature of the persons speaking of them—just as any two nearest mile-stones on a road, although merely marking degrees of the same object, *distance* from a place, might receive from persons living between them the opposite names of east and west, or of north and south. It is to be remarked, moreover, that the sensation of heat is producible also by a body colder than the hand in its ordinary state, provided the body be less cold than some other body touched immediately before, or than the usual temperature in the place; and the sensation of cold is producible under the opposite circumstances of the hand touching a comparatively warm body, but which is less warm than something touched just before. This explains the fact that the same body may at the same time, and to the same person, appear both hot and cold. If a person transfer one hand to common spring water from touching ice, that hand will deem the water very warm; while the other hand, transferred to it from a warm bath, will deem it very cold. For a like reason, a person from India, arriving in England in the spring time, deems the air cold, while the inhabitants of the country may be diminishing their clothing because the heat to them is becoming oppressive. Such facts show how necessary it was for men to find more correct thermometers than their bodily sensations.

"*Spreading partly through their structure, or by conduction, as it is called, with a progress proper to each substance.*" (Read the Analysis, page 406.)

845. If one end of a rod of iron be held in the fire, a hand grasping the other end soon feels the heat coming through it.

Through a similar rod of glass, the transmission is much slower, and through one of wood it is slower still. The hand would be burned by the iron before it felt warmth in the wood, although the inner end of the wood were blazing.

846. On the fact that different substances are permeable to heat, or have the property of conducting it, in different degrees, depend many interesting phenomena in nature and in the arts: hence it was important to ascertain the degrees exactly, and to classify the substances. Various methods for this purpose have been adopted. Thus for solids—similar rods of different substances, after being thinly coated with wax, have been placed with their ends in hot oil, and then the comparative distances to which in a given time the wax was melted, furnished one set of indications of the comparative conducting powers:—or, equal masses of different substances, with a central cavity in each containing a thermometer, being heated to the same degree, and then plunged into the same bath to cool until the thermometer fell in all to a given point, the differences of time elapsed gave still another list.

847. These and other experiments have shown as a general rule, that density in a body favours the passage of heat through it. The best conductors are the metals, and then follow in succession, diamond, glass, stones, earths, woods, &c., as here noted. The numbers standing after the names mark nearly the comparative conducting powers in relation to gold used as a standard and called 10.

Gold	10
Platinum	9¾
Silver	9½
Copper	9
Iron	3¾
Glass and Porcelain	1½
Fire-brick	1
Woods	½
Water and Air, if not moving,	almost 0

848. Count Rumford, to ascertain the relative degrees in which furs, feathers, and other materials used for clothing, conduct heat, or, which is the same thing, resist its passage, adopted this method. He covered the ball and stem of the thermometer with a certain thickness of the substance to be tried, by placing it within a larger bulb and stem of glass, and then filling the surrounding interval between the two with the substance; and after heating this apparatus to a given degree by dipping it in liquid of the desired temperature, he surrounded it by ice, and marked the comparative times required to cool the thermometer a certain number of degrees. The figures following the names

of some of the substances in the subjoined list, mark the number of seconds required respectively for cooling down the so placed thermometer through sixty degrees of Fahrenheit.

Sewing-silk	917
Wood-ashes	927
Charcoal	937
Fine lint	1,032
Cotton	1,046
Lamp-black	1,117
Wool	1,118
Raw silk	1,284
Beavers' fur	1,296
Eider down	1,305
Hares' fur	1,315

849. Air stands in the list, Art. 847. If its particles are not allowed to move about among themselves, so as to *carry* heat from one part to another, it *conducts* (in the manner of solids) so slowly that Count Rumford doubted whether it conducted at all. It is probably the worst conductor known, that is, the substance which when at rest impedes the passage of heat the most. To this fact seems to be owing, in a considerable degree, the remarkable non-conducting quality of porous or spongy substances, as feathers, loose filamentous matter, powders, &c., which have much air in their structure, often adherent with a force which immersion in water, or even being placed in the vacuum of an air-pump, can scarcely overcome.

850. While contemplating the facts set forth in the above table, one cannot but reflect how admirably adapted to their purposes the substances are which nature furnishes as clothing for the inferior animals;—and which man afterwards accommodates with such curious art to his peculiar wants. These animals required to be protected against the chills of night and the keen blasts of winter; and some of them which dwell among enduring ice, could not have lived at all, but for a garment which should shut up within them nearly all the heat which their vital functions produced. Now any covering of a metallic or even a woody nature, would have been far from sufficing; but out of a chemical union of carbon with the soft ingredients of the atmosphere, those beautiful textures are produced called fur and feather, so greatly adorning while they perfectly protect the wearers:—textures, moreover, which grow from the bodies of the animals, in quantity exactly suiting the climate and season, and are reproduced when by use or wear they become too thin. In warm climates the hairy coat of quadrupeds is comparatively thin: as of the elephant, the monkey, the tropical sheep, &c. It is seen to thicken as the temperature is lower, furnishing the abundant fleeces of the temperate zones; and

towards the poles it is externally shaggy and coarse, and internally shorter and fine, as in the arctic bear, &c. In amphibious animals, which have to resist the cold of water as well as of air, the fur acquires a peculiar character, as in the otter and beaver. Birds, from having very warm blood, required plenteous covering, but required also to have a smooth surface, that they might pass easily through the air:—both objects are secured by the marvellous structure and arrangement of feathers. Feathers, like fur, appear in kind and quantity suited to particular climates and seasons. The birds of cold regions have plumage almost as bulky as their bodies; and those of them which live much in the water have, additionally, both a defence of oil on the surface of the feathers, and the interstices of the ordinary plumage filled up by the still more delicate structure called down, particularly on the breast, which in swimming first meets and divides the cold wave. There are animals with warm blood which yet live immersed in water, as the whale, seal, walrus, &c.;—and neither hair nor feathers, however oiled, would have been a fit covering for them; but they are furnished with an equal protection in the vast mass of fat or blubber which surrounds their bodies, which is another substance, it may be remarked, scarcely less useful to man than the furs and feathers of land animals.

While speaking of clothing, we may observe that the bark of trees is also a structure slowly permeable to heat, and guarding, therefore, the temperature necessary to their vegetable life.

851. And while we admire what is done for animals and vegetables, let us think of the important protection of snow and ice, as winter clothing for the fields and gardens, for the lakes and rivers. Ice, as a protection to water and its inhabitants, was considered at page 201 in the explanation of why, although solid, it swims on water. We have now to remark that snow, which may be called the pure white fleece of the earth is a structure which resists the passage of heat nearly as much as feathers. Snow, of course, has to defend only from colds below 32° or the freezing point; but it does that most effectually, preserving the roots and seeds and tender plants during the severity of winter. When the green blade of wheat and the beautiful snow-drop appear in spring rising through the melting snow, they have recently owed an important shelter to their wintry mantle. Under deep snow, while the thermometer in the air may be far below zero, the temperature of the ground

rarely remains below the freezing point; and this temperature, to persons who have to bear sharper cold in the outer air, is mild and even agreeable. It is much higher than what often prevails for long periods in the atmosphere of the north of continental Europe. The Laplander, who during his winter lives chiefly under ground, is glad to have additionally overhead a thick covering of snow. Among the hills of the north and west, even of Britain, during the storms of winter, a covering or shelter formed of snow frequently preserves the lives of travellers, and even of whole flocks of sheep, where the keen north wind finding them unprotected, would soon extinguish life.

852. It is because earth conducts heat slowly, that the intense frosts of winter and the direct sunbeams of summer penetrate but a short way into it. The temperature of the ground, a few feet below its surface, is nearly the same all the year round. At the depth of 100 feet, the temperature of the earth shows everywhere the average temperature of the climate, differing, of course, with the latitude. In England, it is 52° ; at Grand Cairo, 70°. In deep mines the thermometer does not vary one degree in a twelvemonth. In a cellar, at a depth of 80 feet, under the Astronomical Observatory of Paris, a thermometer placed has not varied half a degree during 200 years.—Thus also, water in pipes which are laid two or three feet under ground, as in the streets of cities, does not freeze, although it may be frozen in all the smaller branches exposed above. Hence, again, springs of water do not freeze, and therefore often become remarkable features in a snow-covered country; the living water, after issuing from the bowels of the earth, is seen running a considerable way through fringes of green, before the frost can arrest it; and around the stream, as is well known to sportsmen, the snipe and wild duck and other birds are wont to congregate. A spring at the bottom of a frozen pond or lake may cause the ice to be so thin over it, that a skater arriving there may break through. The same spring water which appears warm in winter, is deemed cold in summer, although always of the same heat, because in summer it is compared with the warmer atmosphere and objects. In proportion as buildings are massive, they acquire more of the quality of uniform temperature here spoken of. Many of the Gothic halls and cathedrals are called cool in summer and warm in winter—as are also old-fashioned houses or castles with thick walls and deep cellars. Natural caves in the mountains or the sea-shores furnish other examples of the same kind.

853. When in the arts it is desired to prevent the passage of heat out of or into any body or situation, a covering of a slow conducting substance is employed. Thus, to prevent waste of heat from a smelting or other furnace, it is lined with fire-bricks, and thickly covered with a kindred material. A furnace so guarded may be touched by the hand with impunity, even while having within it melted iron. To prevent, during the winter, the freezing of water in pipes, by which occurrence the pipes would be burst, it is common to cover them with straw-bands or coarse flannel, or to enclose each in a larger outer pipe, the interval between the two being filled up with dry charcoal, or sawdust, or chaff. If a pipe, on the contrary, be for the conveyance of steam or other warm fluid, the heat in it is retained, and therefore saved by the very same means. Ice-houses are generally made with double walls, between which dry straw is placed, or sawdust, or air, to prevent the passage of heat. Pails for carrying ice in summer, or intended to serve as wine-coolers, are guarded on the same principle. A flannel covering keeps a man warm in winter—it is also powerful to keep ice from melting in summer. Urns for hot water, tea-pots, coffee-pots, &c., are made with wooden or ivory handles, because, if metal were used, it would conduct the heat so readily that the hand could not bear to touch them.

854. It is because glass and earthenware, which are brittle, do not allow a ready passage to heat, that vessels made of such material are so frequently broken by sudden change of temperature. On pouring boiling water into such a vessel, the internal part is much heated and expanded (as will be explained more fully in a subsequent page) before the external part has felt the influence, and the latter is hence riven or cracked by its connection with the other. A chimney mirror is often cracked by a lamp or candle placed on the marble shelf too near it. The glass cylinder of an electrical machine will sometimes be broken by placing it so near the fire, that one side is heated while the other side, receiving a current of air approaching the fire from a door or window, remains cold. A red-hot rod of iron drawn along a pane of glass will divide it almost like a diamond knife. Even cast iron, as in backs of grates, iron pots, &c., although conducting more readily than glass, is often, owing to its brittleness, cracked by unequal heating or cooling, as from pouring cold water on it when hot. Pouring cold water into a heated glass or boiling water into a cold glass will produce a similar

effect. Hence glass vessels intended to be exposed to strong heats and sudden changes, as retorts for distillation, flasks for boiling liquids, &c., are made thin, that the heat may pervade the whole substance almost instantly and therefore safely.

There is a toy called a *Prince Rupert's Drop* (a pear-shaped lump of glass with a slender stalk), which well illustrates our present subject. To make it, the glass, while in a state of fusion or softness, is let fall into water, and is thereby suddenly cooled and solidified on the outside before the internal part is changed; then as the internal part at last hardens and would contract, it is kept unnaturally extended by the arch of external crust, to which it coheres. If a portion of the neck of the lump be afterwards broken off, or if any violence be done which jars its substance, the strained cohesion is destroyed, and the whole mass crumbles to dust with a kind of explosion. Any glass, if cooled suddenly when first made, remains very brittle, for the reason now explained. What is called the *Bologna jar* is a very thick small bottle, so prepared, which bursts when a grain of sand is let fall into it. The process of annealing, to render glass-ware more tough and durable, is merely the allowing it to cool very slowly in an oven, so that the whole may become solid nearly at the same time. The tempering of metals by sudden cooling is a process having some relation to that now described.

855. It is the difference of conducting power in bodies which is the cause of a very common error made by persons in estimating the temperature of bodies by the touch. In a room without a fire all the articles of furniture soon acquire the same temperature; but if in winter, a person move a bare foot from the carpet to the wooden floor, from this to the hearth-stone, and from the stone to the steel fender, his sensation deems each of these objects in succession colder than the preceding;—the truth being, that although all have the same temperature, only a temperature inferior to that of the living body, the best conductor, when in contact with the body, from carrying off heat the fastest, is deemed the coldest. Were a similar experiment made in a hot-house, or in India, while the temperature of everything around were 98°, or that of the living body, then not the slightest difference would be felt in any of the substances. Or, lastly, were the experiment made in a room where by any means the general temperature were raised considerably above blood-heat, then the carpet would be deemed considerably the coolest instead of the warmest, and the other things would appear hotter

in the same order in which they appeared colder in the winter room. Were a bunch of wool and a piece of iron exposed to the severest cold of Siberia, or of an artificial frigorific mixture, a man might touch the first with impunity (it would merely be felt as rather cold); but if he grasped the second, his hand would be severely frost-bitten: were the two substances, on the contrary, transferred to an oven, and heated as far as the wool would bear, he might again touch the wool with impunity (it would then be felt as rather hot), but the iron would burn his flesh. The author of this work once entered a place where there was no fire, but where the temperature from hot air admitted was sufficiently high to boil the fish, &c., of which, in another room, he afterwards partook at dinner; and he breathed the hot air without uneasiness. He could bear to touch woollen cloth in the hot room, but no substance more solid.

856. The foregoing considerations make manifest the vulgar error of supposing that there is a positive warmth in the materials of clothing. The thick cloak which guards a Spaniard against the cold of winter, is also in summer used by him as protection against the direct rays of the sun:—and while in England flannel is our warmest article of winter dress, yet we cannot more effectually preserve ice in summer than by wrapping the vessel containing it in many folds of softest flannel.

857. In every case where a substance of lower temperature than the living body touches it, a thin surface of the substance immediately in contact shares the heat of the bodily part touched—the hand generally; and while in a good conductor, the heat so received quickly passes inwards or away from the surface, leaving this in a state to absorb more, in the tardy conductor the heat first received tarries at the surface, which consequently soon acquires nearly the same temperature as the hand, and, therefore, however cold the interior of the substance may be, it does not cause strong sensation of cold. The hand on a good conductor has to warm it deeply, on a slow conductor to warm only superficially. The following cases farther illustrate the same principle: If the ends of an iron poker, and of a piece of wood of the same size, be wrapped in paper and then thrust into a fire, the paper on the wood will begin to burn immediately, while that on the metal will long resist:—or if pieces of paper be laid separately on a wooden plank and on a plate of steel, and then a burning coal be placed on each, the paper on the wood will begin to burn long before that on the plate. The

explanation is, that the paper in contact with the good conductor loses to the conductor so rapidly the heat received from the coal, that it remains at too low a temperature to inflame, and will even cool to blackness the touching part of the coal; while on the tardy conductor the paper becomes almost immediately as hot as the coal, and burns. It is because water open to the atmosphere cannot be heated beyond 212°, that it may be made to boil in an egg-shell or a vessel made of paper, held over a lamp, without the containing substance being destroyed; but as soon as it is dried up, the paper will burn and the shell will be calcined:—the solder of a common tinned kettle melts under the same circumstances.

858. The reason may here be readily comprehended why a person suffering what is called a cold in the head, or catarrh from the eyes and nose, experiences so much more relief from applying to the face a handkerchief of linen or cambric than one of cotton:—it is, that the former by *conducting* readily absorbs the heat and diminishes the inflammation, while the latter, by refusing to give passage to the heat, increases the temperature and the distress. Popular prejudice once held that there was a poison in cotton.

"*Heat spreads in fluids chiefly by the motion of their particles.*"
(Read the analysis, page 406.)

859. The reason why the hand judges a cold liquid to be so much colder than a solid of the same temperature is, that from the mobility of the liquid particles among themselves, those in contact with the hand are constantly changing. The impression produced on the hand by very cold mercury is almost insufferable, because mercury is both a ready conductor and a liquid. Again, if a finger held motionless in water feel cold, it will feel colder still when moved about: and a man in the air of a calm frosty morning does not experience a sensation nearly so sharp as if with the same temperature there be wind. A finger held up in the wind discovers the direction in which the wind blows by the greater cold felt on the windward side where the shifting of particles is greatest, the effect being still more remarkable, if the finger be wetted. If a person in a room with a thermometer, were with a fan or bellows to blow the air against it, he would not thereby lower it, because it had already the same temperature as the air, yet the air blown against his own body would appear colder

than when at rest, because, being colder than his body, the motion would supply heat-absorbing particles more quickly. In like manner, if a fan or bellows were used against a thermometer hanging in a furnace or hot-house, the thermometer would suffer no change, but the air moved there against a person would be distressingly hot, like the blasting sirocco of the sandy deserts of Africa. If two similar pieces of ice be placed in a room somewhat warmer than ice, one of them may be made to melt much sooner than the other, by blowing on it with a bellows;—as we see the accumulated ice and snows of winter so rapidly melting when the warm south winds of spring begin to blow upon them.

860. Owing to the mobility among themselves of fluid particles, heat entering a fluid anywhere below the surface, by dilating and rendering specifically lighter the portion heated, allows the denser fluid around to sink down and force up the rarer; and the continued currents so established, diffuse the heat through the mass much more quickly than heat spreads by conduction in any solid.

861. Perhaps the best experimental illustration of the subject is obtained by placing a tall glass jar, filled with water in which small pieces of amber or other light substance are diffused to show its movements, first in a warm bath, and then in a cold bath. In the first case, the water and amber near the outside of the jar where they are heated, will exhibit a rapid upward current, while in the centre of the jar they will form an opposite or downward current. In the second case, or when the jar is placed in a cold bath, the direction of the currents will be reversed.

862. Count Rumford's experiments led him at first to conclude that liquids, but for this carrying process of the particles changing their place, were absolutely impassible to heat. A piece of ice may be held long unaffected at the bottom of water which is made to boil at the top by the contact of any hot body, or by alcohol poured out upon it and set fire to.

863. The internal currents or circulation produced by heat in fluid masses, and of which there are so many important instances in nature, were fitly explained in the chapter on *hydrostatics* and *pneumatics*. The reader may here review the articles 505, and 665 to 670, on winds and other atmospheric phenomena, and on sea currents, &c.

864. As stated in a preceding chapter, it is the heating and dilatation of the fluid air over a tropical island while acted upon

during the middle of the day by the powerful rays of the sun, which allow the colder and heavier air from the face of the ocean around to press inwards upon it, and force it upwards in the atmosphere—the cold current forming the delightful sea-breeze of the climate. And it is such general heating of the air over the whole equatorial belt of the earth, which, rendering it specifically lighter than the air nearer the poles, allows this to assume the form of cool trade-winds, constantly blowing towards the sun's path, and pressing upwards the hot air, which then spreads away on the top of the atmosphere towards the poles to mitigate the severity of the northern and southern cold. In the watery ocean also there is a circulatory motion of the same kind, although less in degree, tending to distribute heat and equalize temperature, and contributing to produce some of the great sea currents known to mariners.

865. The vertical currents produced by heat and cold in the ocean, and in great masses of water generally, maintain in and over them a comparatively uniform temperate freshness, while the rocks and soil on the shores around may be either parched under a burning sun, or bound up in frost. A keen frost chills, and soon hardens in icy grasp the surface of the ground; but of water similarly exposed, the part first cooled descends to the bottom by its increased density, and forces up warmer water to take its place and to diffuse heat: this in its turn is cooled and descends, and a continued circulation is established, so that the surface cannot become ice until the whole mass, of whatever depth, has been cooled down to considerable density. Hence the very deep sea is not frozen even in the coldest climates; and in temperate climates the severest winter freezes only superficially lakes of ordinary depth. During this intestine movement in the water, that which ascends to the surface to be cooled, by losing one degree of its heat, warms more than 500 times its bulk of air one degree, and thus tempers remarkably the air passing over it. Hence places in the vicinity of the sea and of lakes are warmer in winter than places farther inland, although nearer to the equator. England is much warmer in winter than central Germany, which lies south of England; and the coasts of Scotland and the north of Ireland may be warmer than London:—snow never lies long upon these coasts. As continental or inland countries have thus in winter an extreme of cold, so have they in summer an extreme of heat. Water admits the rays of the sun, and absorbs the heat into the thick-

ness of its mass, and therefore is warmed very slowly; but the dry earth, because a slow conducter, retains all the heat near its surface, and is therefore soon heated to excess.

866. The ordinary ventilation of our dwellings and places of assembly is owing to the motion produced by the changed specific gravity of air when heated. The air which is within the house, owing to fires, the respiration of inmates, &c., becomes warmer than the external air, and the latter then presses in at every opening or crevice, to displace or force up the other.* The ventilation of the person by the slow passage of air through the texture of our clothing is a phenomenon of the same kind; and thicker clothing keeps warm chiefly by diminishing the rapidity of this passage. Hence an oiled-silk or other air-tight covering laid on a bed, has greater influence in preserving warmth than one or two additional blankets, and is not generally used, only because it prevents ventilation, and, by shutting in the insensible perspiration, soon produces dampness. From the part of the bed-clothes immediately over the person there is a constant outward oozing of warm air, and there is an oozing inward of cold air in lower situations around. . . . In some persons the circulation of the blood is so feeble, that in winter they have difficulty in keeping their feet warm, even in bed, unless with the assistance of bottles of hot water placed there or some like means, and, in consequence, they often pass sleepless nights, and suffer in their general health. In some such cases, a long flexible tube may be used, made of spiral wire covered with leather or cloth, by which a person can send down to his feet his hot breath, and thus supply to them effectually a natural animal warmth, as in a cold day he does to his hands by blowing upon them through his gloves.

867. The power of fluids to diffuse heat being due thus to their power of *carrying*, and not of *conducting* it, the consequence should follow, that any circumstance which impedes the internal motion of the fluid particles, should diminish the diffusing power. Accordingly we find that fluids in general transfer heat less readily in proportion as they are more viscid. Water, for instance, transfers less quickly than spirits; oil than water; molasses or syrup than oil: and water thickened by starch dissolved in it, or which has its internal motion impeded by feathers or thread immersed in it, much less quickly than where it is pure and at liberty. Cooling being merely a motion the

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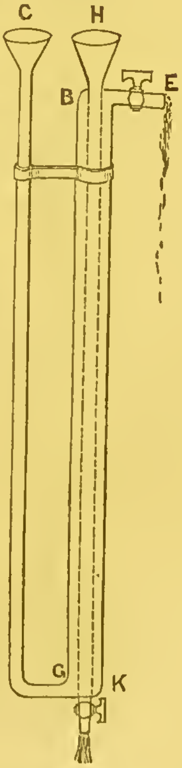
* See Articles 653—663.

reverse of heating, it is influenced by the same law. Hence the reason why thick soups, pies, puddings, and all semifluid masses, retain their heat so long—so much longer than equal bulks of water. The same law affords explanation of the facts, that very porous masses and powders, as charcoal, metal filings, sawdust, sand, &c., conduct heat more slowly than denser masses,—their interstices being filled with air, which scarcely *conducts* heat and which, by the structure of the substance, has no freedom of motion or circulation by which it might *carry* the heat.

The Heat Transferrer.

868. In reflecting upon the fact that heat is diffused in masses of fluid, not by simple conduction, as in solid bodies, but chiefly by motions or currents among the particles, produced as above described, by changed specific gravity, and knowing that two equal measures of water having different temperatures, when completely mixed become a double quantity of an exactly intermediate temperature, the present writer perceived the possibility (Art. 507) of causing equal quantities of boiling and freezing water to run past each other, in perfectly distinct although touching channels, in such a manner, that instead of the two becoming of the same middle temperature, the lately boiling should become nearly freezing, and the lately freezing nearly boiling. It seemed strange that this easy operation was not in common use and employed for many important purposes. But it was not unnatural for persons to think that when a measure of hot water had given up half its heat to an equal measure of cold, and had thereby rendered that as warm as itself, no farther change could occur. At first one might not think of the consequences of making the currents run in contrary directions and in vertical channels. The adjoining engravings will explain the new process.

Fig. 1.



Let H K, Fig. 1, be a long tube formed of very thin metal, with a funnel H at the top, into which boiling water can be poured, to issue again below through the regulating cock K. Let B G be a larger tube surrounding the other, and just so much larger as to allow an equal current of nearly freezing water coming from the funnel C, by the tube C G, to enter below at G, and to rise around the smaller tube to be discharged through the cock E. Evidently then, if the tubes be of sufficient length, the lately boiling water descending in the internal tube H K must be losing every instant, and at every point in its course, part of its heat, to the colder ascending current around it, until it has lost the whole of its excess, which being all gained by the equal ascending current, the transference becomes complete. It might at first be supposed that great length of tubes would be required in the experiment; but in truth a length of about one yard suffices to prove conclusively the efficacy of the arrangement.

Fig. 2.

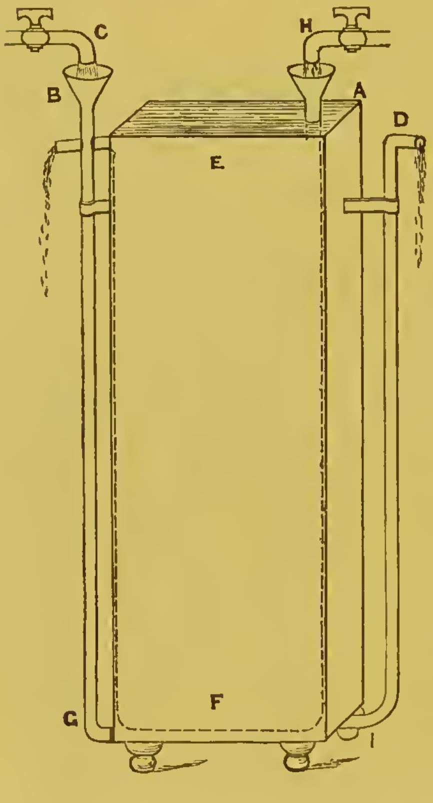
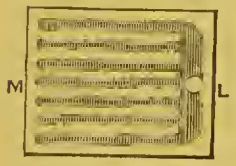


Fig. 2 is only a more capacious repetition of Fig. 1. In it, the channel of the descending hot water, instead of being a single cylindrical tube of narrow surface, through which the heat has to pass from one fluid to the other, has a very extensive surface compressed into small bulk by being corrugated or folded longitudinally upon itself. It so forms many thin flat channels in which the hot fluid descends, while the rising colder fluid occupies similar flat spaces between these; and no particles of the hot fluid can avoid being always close to passing particles of the colder.

Fig. 3 is a section of the parallel columns as viewed from above. The dark spaces mark the hot liquid descending, the light spaces the colder liquid rising. In the larger apparatus, the water which has been cooled is caused to rise from the bottom in the tube 1 D, to be discharged conveniently at D nearly at the level of the other inlets and outlets.

Fig. 3.



Mr. Griffin, of No. 119 Bunhill Row, E.C., London, the skilful manufacturer of Chemical and Philosophical Apparatus, prepares working models of this Heat Transferrer, by having one of which a student planning any useful application of the principle may familiarise himself with the management.

869. Among the purposes which the Heat Transferrer may serve, are the following:

1. Cooling at once the hot wort of Brewers, instead of having to pump it up as of old, to spread on wide expanded cooling floors, where it loses aroma, and may suffer other damage.

2. To lessen the expense of warm-bathing establishments, and of public wash-houses.

3. To facilitate in winter the complete warm ventilation of dwellings, churches, manufactories, halls of assembly, &c., without danger of cold draught, and with small expense of fuel. The transfer of heat takes places between currents of air as it does from liquid to liquid.

4 To allow the formation of a perfect breath-warmer, important to persons of delicate health, in cold weather.

5. To utilize the warmth of smoke in various ways.

Engineers having familiarity with the principle may suggest many forms and applications.

"*Heat spreads also, partly, by being radiated or shot like light, from one body to another, through transparent media or space, with readiness affected by the material and the state of the giving and receiving surfaces.*" (Read the Analysis, page 406.)

870. If a heated ball of metal be suspended in the air, a hand brought in any direction near to it will experience the sensation of heat: and beneath it the sensation would be as strong as on the sides, but that the heat has to meet a current of cool air approaching from below, to rise from it, as explained in a preceding section. A delicate thermometer substituted for the hand will equally detect the spreading heat, and if held at different distances, will prove it to diminish in the same ratio as light diminishes in spreading from any luminous centre, *viz.*, to be only a fourth part as intense at a double distance, and in a corresponding proportion for other distances. If the heated body be enclosed in a vacuum, a thermometer placed near it will still be affected in the same manner. If a screen be interposed between the body and the thermometer, the latter will not be affected at all, proving the heat to spread in straight lines. Heat when dif-

fusing itself in this way, to distinguish it from heat passing by contact or communication, as described in the last section, is called *radiant* heat; that is to say, spreading in radii or rays all round its source, as light spreads.

871. Radiant heat resembles light yet in other respects. It as rapidly permeates certain transparent substances as rock salt, and its course suffers in them the kind of the bending, termed refraction by opticians. It is reflected from many polished surfaces, just as light is reflected from a common mirror; and many such surfaces directed to one point or centre (as when Archimedes in defending Syracuse, caused the sun to set fire to the Roman ships) or a single concave surface, having its one centre or focus, will concentrate the heat with the light. Its motion in the sunbeam is so rapid, as for any distance at which men can try the experiment, to appear instantaneous; and the rays of heat from hot iron or burning charcoal concentrated at great distances by suitable mirrors, affect a thermometer as quickly as the heat of the sun similarly reflected. Although light and heat are united in the sun's ray, they are still separable by our glass prisms or lenses; and the focus of heat behind a burning glass is not precisely the focus of light. Heat in radiating through pure air does not warm the air, and its passage is not sensibly affected by winds or any other motion of the air.—These resemblances in the phenomena of light and heat have by some inquirers been held to prove that the two classes of appearances are only different modifications of action in the same subtle substance or ether.

872. The diffusion of heat by radiation, as it takes place in an instant to any distance, and begins whenever there is any inequality of temperature between bodies exposed to each other, would produce speedy balance of temperature throughout nature, but that heat leaves and enters bodies with readiness depending on the condition of their surfaces, and on their internal conducting powers. A black stone-ware teapot, for instance, filled with boiling water, will radiate away 100 degrees of its heat in the same time that a similar vessel of polished metal will radiate only 12 degrees.

873. Professor Leslie was the first to see the importance of investigating this subject, and he had the merit of contriving well-adapted means, and of detecting many of the important facts. As common thermometers are not sufficiently delicate to determine very sudden changes of temperature, where the in-

fluence is so slight as in many cases of radiant heat, he used the beautiful *differential thermometer* contrived by himself, in conjunction with concave mirrors (as represented in the next page) to concentrate the heat and accumulate its energy. Then taking as his heated body a cubical tin vessel filled with boiling water, and covering it successively with plates or layers of different substances and with different colours, and exposing the thermometer to it for a given time under all the changes, he noted the number of degrees which the thermometer rose (as seen in the table which here follows) and thus ascertained the radiating power of each sort of covering.

Lamp-black	100°	Tarnished lead	45°
Writing paper	98	Clean lead	19
Crown glass	90	Iron polished	15
Ice	87	Tin plate	12
Isinglass	75	Gold, silver, and copper	12

He next reversed the experiments by using his hot-water vessel always in the same state, and covering the thermometer bulb with the different substances and colours, and thus he ascertained that the comparative *absorbing* powers of the substances and colours were very nearly proportioned to their *radiating* powers: lamp-black, for instance, absorbed or was heated 100°, while the polished metals absorbed, or were heated only 12°, and so for the others. And, lastly, the absorbing powers being an indication of the weakness of the *reflecting* powers (for a body absorbing a given proportion of the heat which falls on it, can reflect only the remainder), he by the same experiments ascertained the radiating, absorbing, and reflective or mirror powers of the bodies, and, therefore, all the importnnt points respecting radiant heat in its relation to the different substances.

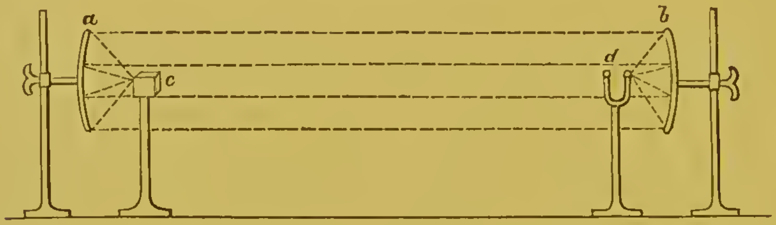
It seems paradoxical that a clothing of a thin cotton or woollen fabric placed on a polished tin vessel, should cause the heat to be received by it or dissipated from it much more than if the vessel were naked and polished, but such is the fact. And metal with a scratched or roughened surface radiates or receives much more rapidly than polished metal.

874. The property of absorbing heat depends partly upon the colour of the substance; and as a general rule the dark colours, *viz.*, those which absorb the most light, absorb also most heat. Dr. Franklin proved this by laying pieces of cloth of different colours on snow, and exposing them during a given period to

the sun's rays, while he noted the different depths to which, by the melting of the snow under them, the pieces sank. Hence the effect of having a white hat in summer, that by it, with the sun's light, the heat also may be repelled. And a white dress in winter is good, because it radiates little. Polar animals have generally white furs. White horses are said to be less heated in the sun, and less chilled in winter, than those of darker hues.

The rate of cooling in heated bodies must be influenced by all the particulars noted above, viz., substance, surface, and colour, and by the excess of heat in the cooling body as compared with those around it.

875. The concentrating apparatus used for experiments on the radiation of heat consisted of two concave tin mirrors, here represented at *a* and *b*, so formed and placed in relation to each other, that all the rays of light or heat issuing from the focus of one, as at *c*, shall, after a double reflection, be collected in the focus of the other, *d*. A stand under one focus *c* is intended to support the body giving out or receiving heat, and a stand under the other *d* is meant to support the thermometer. For further explanation of the action of such mirrors, we may refer to what was said of the concentration of sound in the sections on *Acoustics*, or to what will follow in the section of *Optics*, on the concentration of light. The general rationale of such facts is, that heat, light, sound, an elastic ball, &c., when reflected from any point of a surface, returns if it fall perpendicularly to that point, in the same line by which it approached; but if it fall obliquely, or from one side of the perpendicular, it returns in a line deviating as much on the other side. Now the surface of a spherical concave acts so that every ray issuing from a point which is not the centre of the said concave but half way nearer the surface, shall, when reflected, become parallel to every other ray—as represented by the dotted lines in the figure; and it is the property of a similar mirror receiving parallel rays, to make them all meet in that focus:—thus any influence radiating from *c* towards the mirror *a*, will again,



after two reflections, be collected at *d*. The purpose and effect of such mirrors in experiments on heat, is merely to concentrate feeble influences, so that they may be more accurately estimated. To show the effect and mode of action of such mirrors, they may be placed exactly facing each other at any convenient distance, and then a hot body of any kind, as a metallic ball or a canister of boiling water, being placed in one focus while a thermometer stands in the other, the thermometer will instantly rise; although, if left in any intermediate situation nearer to the hot body, and therefore not in the focus, it will not be sensibly affected. If burning charcoal be placed in one focus and a readily combustible substance in the other, the latter may be set fire to at the distance of thirty feet or more.

876. If in one focus of the mirror-apparatus described above, there be placed, instead of the canister of hot water, a piece of ice, the thermometer in the other focus immediately falls. This has been called the radiation of cold, and persons were at one time disposed to think that it proved cold to be a substance of a different nature from that of heat. The case, however, is merely that the thermometer happens then to be the hotter body, in one focus of the mirrors, brought into close relation with a colder body, the ice, placed in the other, and consequently by the law of equable diffusion, it must share its heat with the ice, and will fall. The mirrors in any case have their effect merely by preventing the spreading and dissipation of some radiant heat from either focus except towards the other, and of making two distant bodies act upon each other as if they were almost in contact or very near. All the heat that seeks to radiate from the thermometer *d* in the direction of the surface of the mirror *b*, if not met by an equal tension or force of temperature in the other mirror or focus to which they are directed at *a* and *c* will radiate away to *c*, and become deficient at *d*. Some inquirers have believed that heat is ever actively radiating in exchange from substance to substance (nearly as light radiates between two opposed burning lamps), only more copiously from the side where the temperature was highest: others have held that motion takes place only where there is excess of heat; that is, when the balance of temperatures is destroyed; and this is the simpler view.

877. Different substances allow passage to rays of light more or less readily, and accordingly are said to have different degrees of transparency, as in the series from pure air, glass, water, &c.

at one end, to paper, thin porcelain, stones, &c. at the other; so different substances influence very differently the passage of rays of heat. But what might not be expected, certain substances which transmit light freely are found to obstruct heat, as crystals of pure alum, while some which obstruct light, as black glass, give free passage to heat. Another remarkable fact is, that heat from a source of great intensity, like the sun, passes readily through many things, as glass, and water, which absorb and arrest heat-rays from sources of lower temperature, as hot stones or liquids. Rock salt has the remarkable property of allowing the heat-rays of both kinds to pass with equal readiness.

878. It is important to remark here that because water or moisture offers considerable obstruction to the passage of heat-rays from sources of low temperature, the state of the atmosphere as to moisture near the surface of the earth, influences much the temperature existing there. The sun's heat-rays come down readily, not only through the dry atmosphere of great elevations, but also through the humid air below, while the return radiation from the moderately heated earth being resisted by the moisture, useful warmth is retained below. Unimpeded radiation, through perfectly dry clear air during a single night might chill ordinary vegetation very destructively. Dr. Tyndall had lately the merit of directing attention to this fact. In our drawing-rooms it is common to have plate-glass fire-screens, which, while they allow the light to pass, defend the face from the heat: but all persons know that the heat of the sunbeams, as well as their light, enters our green-houses through the glass which covers them. A glass screen interposed between the concave mirrors in the apparatus above described, destroys almost entirely the effect of the heated body placed in one focus, on the thermometer in the other, and the trifling effect really produced appears to be owing to the heat that is absorbed by one side of the screen, and then, after passing through it by conduction, is radiated from the other. This conclusion is supported by the fact that screens of metal or of glass, covered with lamp-black, paper, &c., allow transmission nearly in proportion to their several absorbent and radiant powers.

879. The doctrines of radiant heat make us aware of the importance of having vessels of polished metal for containing liquids or other things which we desire to keep warm; hence tea and coffee-pots, &c., should be polished. As a black earthen tea-pot loses heat

by radiation nearly in proportion to the number 100, while one of silver or other polished metal loses only as 12, there will be a corresponding difference in their aptitude for extracting the virtues of any substance infused in them. Pipes for the conveyance of steam or hot air, if left naked, should be of polished metal; but after arriving at a place where they have to give out their heat, their surface should be blackened and made rough. A coat of polished mail is not a very cold covering. A mirror intended to reflect heat should be of highly polished metal, and such, for an obvious reason, the interior of a screen placed behind roasting meat at a kitchen fire should be. A fireman's mask is usually covered externally with smooth tin foil. It is of advantage that the bottom of a tea-kettle or other cooking vessel be externally black, because the bottom has to absorb heat, but the top should be polished because it has to confine.

880. The interesting phenomenon of dew (Art. 640) was not at all understood until lately, since the laws of radiant heat have been investigated. At sunrise in particular states of the sky every blade of grass and leaflet is found, not wetted, as if by a shower, but studded with a row of distinct globules most transparent and beautiful, bending it down by their weight, and falling like pearls when the blade is shaken. These are formed in the course of the night by a gradual deposition on leaves of vegetables and other bodies rendered by radiation colder than the air around them, of part of the moisture which rises invisibly from water surfaces into the air during the heat of the day. In a clear night the objects on the surface of the earth radiate heat to the sky through the air which impedes considerably, as explained in Art. 878, but does not altogether prevent the radiation, while there is nothing nearer than the stars to return radiation; they consequently soon become colder, and if the air around has its usual load of moisture, part of this will be deposited on them in the form of dew, exactly as the invisible moisture in the air of a room is deposited on a cold bottle of wine when first placed on the table. Clouds, by obstructing the radiation spoken of, obstruct the formation of dew. Air itself seems to lose little heat by radiation. A thermometer placed upon the earth any time between sunset and sunrise, generally stands considerably lower than another suspended in the air a few feet above it; owing to the radiation of heat upwards from it and from the earth, while the surrounding air remains nearly in the same state. During the day, while the sun shines, the earth

is much warmer than the air. The reason why the dew falls, or is formed so much more copiously upon the soft spongy surface of leaves and flowers, where it is wanted, than on the hard surface of stones and sand, where it would be of no use, is the difference of their radiating powers. There is no state of the atmosphere in which artificial dew may not be made to form on a body by sufficiently cooling it, and the degree of heat at which the dew begins to appear is called the *dew-point*, being an important particular in the meteorological report of the day. In cloudy nights heat is radiated back from the clouds, and the earth below not being so much cooled, the dew is scanty or deficient. And it is, when uninformed persons would least expect the dew, namely, in warm very clear nights, and perhaps when the beautiful moon invites to walking—as in some of the evenings of autumn with the harvest moon and harvest occupations—that the dew is more abundant and the danger greater to delicate persons of taking harm by walking among the grass.

"*Heat by entering bodies expands them, and through a range which includes as three successive stages the forms of solid, liquid, and air or gas; becoming thus in nature, the grand antagonist and modifier of the effects of that attraction which holds corporeal atoms together, and which, if acting alone, would reduce the whole material universe to one solid lifeless mass.*" (Read the Analysis, page 406.)

881. If an experimenter take a body which is as free from heat as human art can obtain it—a bar of solid mercury, for instance, as it exists in a polar winter—and if he then gradually heat such body, it will acquire an increase of bulk with every increase of temperature; first, for a time, there will be simple enlargement or expansion in every direction; then the mass will in addition be softened; then it will be melted or fused, that is to say, in the case supposed, the solid bar will be reduced to the state of liquid mercury, with the cohesive attraction of the atoms nearly overcome; if the mass be still farther heated, it will continue to gain bulk until at a certain point, some of the atoms will be suddenly repelled from the mass and from one another to much greater distances, constituting then a very elastic fluid called an air or gas, many hundred times more bulky than the same matter in the solid or liquid state, and capable of very forcibly distending an enclosing vessel, as com-

mon air distends a bladder; susceptible, moreover, of dilating indefinitely farther, by farther additions of heat, or by diminution of the atmospheric or other pressure, against which it had to expand during its formation. A subsequent removal of the heat from the gaseous fluid will occasion a progress of contraction corresponding to the previous progress of expansion, and the various conditions or forms of the substance above enumerated, will be re-produced in a reverse order, until the solid mass re-appear, as at first.

882. What is thus true of mercury is proved by modern chemical art, to be true also of all the ponderable elements of our globe, and of many of the combinations of these elements, —as water, for instance, familiarly known in its three forms of *ice*, *water*, and *steam*; although compound substances generally, by great changes of temperature, are decomposed into their elements.

883. A student might at first have difficulty in believing that the beautiful variety of solid, liquid, and air found among natural bodies, could depend upon the quantities of heat in them, because these forms are all seen existing at the same common temperature; but he afterwards learns that each substance has its peculiar relation or affinity to heat, and that hence while at the medium temperature of the earth, some bodies contain so little as to have solid form—like the metals, stones, earths, &c.; others have enough to be liquids—as mercury, water, oils, &c.; and others have enough to be airs—as oxygen, nitrogen, hydrogen, &c. Men, until better informed, are prone to deem the states in which bodies are most frequently observed by them, to be the natural or essential states of such bodies; and the Indian king reasoned but in the usual way, who held the Dutch navigators newly arrived on his shores, to be gross impostors, because they said that in their country, at one time of the year, water became so hard that they could walk upon it and drive their carriages upon it, and shape it into solid blocks. All persons err like this king, who in thinking of the different substances familiarly known to them, regard their accidental state of solid liquid or gas, dependent on the climate or situation on earth where they are found, to be an essential natural character.

884. The degrees in a general scale of temperature at which the substances most important to man change their states from solid to liquid, or from liquid to air, will be noted in a future

page. Here we shall only remark that the differences are very great. Mercury is solid when 72 degrees colder than melting ice, and porcelain is fluid when at about 30,000 degrees above that. There are some substances which require so high a temperature for their fusion that human art has difficulty to produce the changes by simple concentration of heat; but all such substances are quickly reducible to the liquid form when placed in contact with others for which they have a chemical affinity, and which have already the form of fluid: as when gold and platinum are dissolved in *Aqua Regia*—flint in the fluoric acid, —carbon in hydrogen gas. One may not reflect that the dissolving of a solid in any fluid menstruum is merely another mode of melting it by heat: but this is the fact, for the menstruum is itself fluid, only because of the much heat which it contains; and in dissolving the more obdurate substance, it does so merely because its attraction for the substance makes it share with the particles of that, the heat which already existed in itself. The influence of heat in this view is seen also in the fact that a fluid when heated can dissolve much more of a solid than when cold. Water while hot can keep dissolved in it much more of any salt than when its temperature has fallen, as is proved by the crystals of salt formed in any saturated solution while cooling. Heat, then, is the one universal solvent or cause of fluidity. This statement is not opposed to the notion that heat may be an oscillatory motion among the ponderable particles of the heated body, accompanied by similar motion in a subtile elastic medium pervading space, which medium may be locally either accumulated or deficient, as many believe the same or a like medium to be, in a Leyden jar or a battery when charged with positive or negative electricity.

885. There are in nature many substances having such affinity for heat, that until lately, they have been known only in the state of gases; and even in the present advanced condition of experimental art, they cannot by any degree of mere cooling be reduced to the liquid or solid form; but many of these, when pressure is added to cooling, or when the chemical attraction for them of some other substances which already exist in the fluid state, is made to co-operate, may be reduced. Instances are seen when carbonic acid gas is by cold and pressure reduced first to the liquid and then to the solid form, or when oxygen gas becomes part of the heavy liquid called sulphuric acid, or of any solid oxide.

886. Of solids, some on receiving heat become very soft before they are liquefied, as pitch, glue, glass, iron, &c.; others change completely at once, as ice does in becoming water; and some pass at once to the state of air, without therefore having assumed at all the intermediate state of liquid. These last are *sublimed*, as it is called, and on cooling again may be caught in a powdery state, as seen in that form of sulphur, or of benzoin, termed the *flower* of the substance. Of this class also are camphor, arsenic, corrosive sublimate, and the substance called iodine, which last, from the state of rich ruby crystals, becomes at once, on being heated, a dense transparent gas of the same hue, and in cooling resumes its crystalline form.

The reader having arrived at this place, may peruse again with advantage the pages near the beginning of this work, from Art. 44 to 55, which treat of the influence of heat on the *constitution of masses.*

> "*Each particular substance, according to the nature and arrangement of its ultimate particles, takes a certain quantity of heat (said to mark its* CAPACITY) *to produce in it a given change of temperature or calorific tension.*" (Read the Analysis, page 406.)

887. A pound of water, for instance, that its temperature may be raised one degree, takes thirty times as much heat as a pound of mercury. This may be proved in various ways. First, if the heat be derived from any uniform source, the water must remain exposed to it thirty times as long as the mercury. Second, if both substances, after being equally heated, are placed in ice until cooled to the freezing point, the heat which escapes from the water will melt thirty times as much ice as that which escapes from the mercury. Third, when a pound of hot water is placed with a pound of cold mercury, instead of the two becoming of a middle temperature, as is the case when equal quantities of hot and cold water are mixed, and every degree of heat lost by the one quantity becomes just a degree gained by the other—the pound of hot water, by giving up one degree to the pound of cold mercury, raises the temperature of the latter thirty degrees; and in the same proportion for other differences:—or on reversing the experiment, a pound of hot mercury will be cooled thirty degrees by warming a pound of water one degree.

888. Now each particular substance in nature, just as water or mercury, has its peculiar capacity for heat; and experiments made by such modes of mixture and of melting ice as above described have led to the construction of tables which exhibit the relations. The following table shows the comparative capacities of equal weights of some common substances. Water, of which the capacity is greater than of any other substance except hydrogen, for reasons of convenience, has been chosen as the standard of comparison. It appears that a pound of hydrogen gas takes about three and a half times more heat to produce in it a given change of temperature than a pound of water, while a pound of mercury or gold takes about thirty times less.

Table of Specific Heats

Stating the comparative quantities of heat required to raise equal weights of the different substances through the same range of temperature.

Water	100	Iron	11
Alcohol	70	Silver	6
Ether	66	Mercury	3
Olive oil	52	Gold	3
Charcoal	24	Hydrogen gas	340
Sulphur	20	Common air	24
Glass	19	Oxygen	22

889. If we seek a reason or reasons why there should be among bodies the differences of capacity here stated, the circumstances chiefly attracting attention are the following: 1st. Equal weights of the various substances have very different bulks or volumes, and therefore seem to have different room in which (if there be a compressible elastic medium concerned, Art. 884) the heat may lodge, or oscillations of particles may play ;—as a pound of mercury, for instance, is only one-thirteenth and a half parts as bulky as a pound of water. That the bulk, however, is not the only influencing circumstance appears in the fact that mercury has one-thirtieth of the capacity of water. 2nd. In equal bulks of different substances, the space may be more completely occupied by the particles of one than of another—as is probably true of the particles of mercury compared with those of water. The influence of bulk or volume, in determining the capacity for heat, is shown in many other facts. In the table, for instance, it is seen that hydrogen and the gases

generally, with their great comparative bulk, have also great capacity; that liquids have less capacity than gases; that solids have less than liquids. Yet the capacity is not in strict proportion to bulk; for hydrogen, which is many thousand times more bulky than an equal weight of water, has only three and a half times the capacity. Then, if any body whatever be suddenly compressed into less bulk, heat spreads from it as if squeezed out. Thus iron or other metal suddenly condensed by the heavy blow of a hammer is thereby rendered hotter. Water and alcohol on being mixed, occupy less space than when separate, and there is from the mixture a corresponding discharge of heat. This truth is most remarkably exemplified in airs or gases, owing to their great range of elasticity. They may be condensed or dilated a hundred-fold or more, and there will be a simultaneous concentration or diffusion of their heat; that is to say, the production, in the space occupied by them, of intense heat or cold. The heat of air just condensed, or the cold of that which has just expanded, is greater for the instant than the most quickly answering thermometer indicates, for there is so little heat even in a considerable volume of air, that the mass of a mercurial thermometer absorbing a great part of it would be little affected. The extent of the change of temperature, however, is seen in the facts, that by the sudden condensation of air we may set fire to tinder immersed in it, and by allowing air suddenly to expand, we may convert any watery vapour diffused through it into ice or snow. It might be expected that air suddenly compressed into half its previous volume, should become just twice as hot as before, or if suddenly dilated to double volume, should be only half as hot; but the facts do not accord with this anticipation, as will be stated in a future page.

890. The different capacity for heat of air in different states of dilatation, produces effects of great importance in nature as well as in the arts—thus,

On the surface of the earth near the sea-shore, the air of the atmosphere has a certain density—a cubic foot weighs about one ounce and a third—dependent on the weight and pressure of the superincumbent mass acting on its elasticity; but on a mountain top 15,000 feet high, where nearly half the mass of the atmosphere is below that level, the air is bearing but half the pressure, and consequently any quantity of it has nearly twice the volume of an equal quantity at the sea-side, with a temperature consequently many degrees lower. The air which is at any time on a mountain top, may, a little while before, have been on an adjoining low plain, or the sea-shore, and in gradually climbing the mountain side as a wind, it must have been gradually expanding and becoming cooler because of the diminishing pressure. It is found that air on rising from the sea-shore, becomes one degree colder nearly, for the first 250 feet of perpendicular ascent, and that air becomes altogether about 50° colder in rising 15,000 feet; so that at this latter elevation, water exposed to the air becomes ice even near the equator, where the temperature of low plains is at least 80°. It thus appears that if a man could travel with the wind so as to remain surrounded always by the same air, he might begin his journey with it in the summer vineyards of the Rhine, might soon after find it the piercing blast of alpine summits; and later still, without any change having occurred in the absolute quantity of its heat, might feel it as the warm breath of the flowers on the plains of Italy.

891. The explanation is thus given of why very elevated mountains in all parts of the earth are hooded in perpetual snows. We have said that even at the equator, where the average temperature near the sea is 84°, water will be frozen when carried to an elevation of 15,000 feet. A line, therefore, traced round a moutain at this level would divide the portion of it destined to rest under lasting ice and snow from the portion below covered with green herbage and trees. This line, where-ever found, is called the *snow line*, or *line of perpetual congelation.* At the equator it is high in the atmosphere, because there is a difference of about 50° between the average temperature of the country and the freezing point of water, *viz.*, the difference between 84° and 32°, and an elevation of 15,000 feet corresponds to this difference; but in a progress towards the poles, the line is met with gradually nearer to the earth, as the difference between the average temperature and the freezing point is less. In parts of tropical America, on the Andes, and on the Himalaya Mountains in Asia, the snow-level is found higher than 15,000 feet above the sea. In Switzerland, it is at a height of from 6000 to 9,000 feet; in Norway, it is below 5,000. With respect to this line of congelation, it is further to be remarked, that in tropical countries, because the temperature of the air is nearly uniform during the whole year, the line or limit of frost and snow is distinct and unvarying, that is to say narrow, particularly where the acclivity is considerable; but in countries to the north and south, which have strong contrast of summer and winter, the line rises

in summer and falls in winter, and thus becomes broad and less evident: in the hot season much snow is melted above the middle of the line or belt, while in winter much snow and ice are accumulated below that, to be melted again when summer returns.

Glaciers.

892. We may here consider the striking phenomenon of what are called glaciers, formed among mountains which rise above the snow-level of the region. When snow, falling on these mountains, as it does, through both summer and winter, accumulates on their sides beyond a certain degree, it breaks loose and slides down in masses called avalanches into the hollows and valleys below, and there, owing to the great pressure and partial meltings, it soon becomes solid ice, called a glacier, often hundreds of feet in thickness or depth. One of the singular facts connected with these masses is, that they have a slow onward motion toward the lower country, as if they were of semi-fluid substance, like soft pitch or yielding clay. It had been noted by the inhabitants around, that huge pieces of rock fallen from bordering heights to the surface of the ice, seemed to have a gradual onward motion towards the lower country, but only of late have scientific men ascertained that the whole mass of the glacier has such motion, carrying the rocky fragments on its surface. Then experiment shows that if a block of ice is crushed and broken by great pressure, and the pressure is continued afterwards, the fragments all perfectly re-unite to become as solid a mass as before, and in any new form which the resisting sides of the containing space may give. Now glacier-ice in a sloping valley is undergoing, by the pressure of its weight, a constant bruising and general internal fracture of its substance, as it is forced along in its irregular channel, and the displaced parts are being as constantly re-united into a solid mass. Glaciers from smaller valleys meet and join with those in the larger, just as smaller streams of water meet to form large rivers. It is interesting to observe that the constantly falling fragments of rock and earth from the elevations around the moving glacier form continuous lines on the surface along the margins to the termination of the glacier, where the increasing warmth of the low country is causing the glacier ice to melt and disappear, and the earthy loads there deposited form ridges or embankments, called moraines, of vast magnitude, crossing the mouth of the valley, the stupendous gather-

ings of bygone ages. The continual and rapid waste of glaciers going on below the level of the snow-line confines those of temperate regions to high positions among the mountains, but in colder regions towards the poles, glaciers extend down, not merely to the sea-shores, but often project far into the sea. When such projections break off, they become the so-called *icebergs* met floating away from the places of their origin.

893. Although the proofs are not at once apparent, the line of congelation exists as truly everywhere in the open sky, over sea and plains, as where there are mountain heights to wear its livery; and considerably below the line, the cold, aided probably by electrical agency, is sufficient to produce, in the form of mist or clouds, a copious separation from the air of the watery vapour contained in it. There is thus in nature an admirable agency at work to shade the surface of the earth at times from the too powerful rays of the sun, and to supply rain as wanted, without the transparency of the inferior regions of the atmosphere being much affected. As the watery evaporation rising from sea and lake, and invisibly diffused in the atmosphere, can reach only to the height where the cold is intense enough to condense it, the clouds may in general be regarded as the high stratum of that atmosphere of watery vapour or aëriform water, which is always mixed more or less with the atmosphere of mere air: and as the quantity of watery vapour which can exist invisibly in a given space, depends altogether on the amount of heat present, the clouds in a cold or a humid atmosphere will generally be low, and in a warm or a dry atmosphere will be high, or there may be none. An aëronaut mounting in his balloon through a clear sky, often enters a dense cloudy stratum, and for a time is surrounded by the gloom almost of night, the face of the earth below being completely hidden from him, while the heavenly bodies are equally veiled from him above; but rising still higher, he again emerges to brightness, and looks down upon the fleecy ocean rolling beneath, as a climber to a very lofty peak looks down from the pure atmosphere around it on the inferior region of clouds and storms.

894. The diminished temperature of air in the higher regions of the atmosphere, often enables the natives of temperate climates, when obliged to reside in hot countries inimical to their health, to find near at hand, on some mountain height, the congenial temperature of their wished-for homes. The writer of this during a visit in early life to the then recently occupied

island of Penang in the strait of Malacca, noted this fact with pleasure not readily forgotten. The centre of the island is much elevated and thickly wooded. On the northern summit there were then a few residences visible from the sea-shore like eagles' nests on a cliff. Towards these, one morning at sunrise, on an active little horse of the country, and along a tolerable road, he began to climb from the hot plain below. At first he had around him merely tropical objects of vegetable and animal kinds; but as he gradually ascended, the character of all seemed to be changing, and the air was becoming so fresh as strongly to recall thoughts of distant England. When he had reached the summit, however, and through an open space he could use the telescope, he seemed to be present in two climates at once. The naked eye could take account only of sunny strait, and distant hills on the continent, such as might be seen in Europe; but, on closer inspection, and with the aid of the telescope were descried the endless variety of tropical objects, —the broad-leaved palms, groves of cocoa-nut and banana, the plantations of sugar-cane, the tawny labourers, the bamboo dwellings, the Malay canoes or prows, and other things of the like character. And this scene, only a few degrees from the equator, a person could have under his eye, while the thermometer near him stood as in England during the month of May.

The interiors of many tropical lands have situations of great extent, which combine, as above described, the advantages of tropical situation and temperate climate, and which might well be inhabited by European colonists. The vast table land of Mexico, and much of the central land of South America, is similarly circumstanced. It is not uncommon, where the ascent to such land is rapid, to find near the bottom towns with their markets stored only with the productions of the equator, while higher up are seen also what belong to the temperate skies of Europe. In the province of Valentia, in Spain, invalids needing temperate climate can find it near the sea-level during winter, and in summer can climb the hills to enjoy the cool atmosphere which befits them.

The facts detailed in the preceding paragraphs illustrate the subject of the relation of *volume* in a body to the capacity for heat, by the change of capacity produced in the same quantity of air according as it is more or less either dilated or compressed. We have now to speak of permanent *density* in the same respect.

895. It might be anticipated that a dense body, or one in

which the constituent particles may be supposed to fill more completely the space occupied by it than the particles do in a rarer body, would have smaller capacity for heat, in proportion to the smaller space left vacant in its mass: and in a general comparison of the capacities of *equal bulks* of different substances such anticipation is partly verified. The relation, however, is by no means universal, nor at all in proportion to the differences of density—for water, which is denser than oil, has twice as much capacity for heat.

896. The relation then between various substances and heat, which we call capacity for heat, depends much more on the nature of the ultimate particles of the substances than either on the absolute bulk or comparative density of the masses. Throwing light on this subject, it has been ascertained that all material substances are composed of extremely minute unchangeable atoms, of which, in the different substances, the comparative weights have been determined (Art. 42), although not the absolute weights; that is to say, for example, the atom of gold is known to weigh nearly six times as much as the atom of iron, although we do not know how many thousands or millions of atoms are required to form a grain of either. And recent researches prove that the capacities for heat, or the specific heats of simple bodies, are inversely as their atomic weights, the two numbers multiplied together, therefore, being a constant quantity.

Instead of the term *capacity for heat* used in the preceding pages, with respect to particular substances, that of *specific heat* has by some authors been preferred; but as the latter gives to a commencing student the idea rather of *kinds* of heat than of *quantities*, the term capacity has been here retained.

> "*Each substance in nature, for a given change of temperature, undergoes expansion in a degree proper to itself, the expansion generally increasing more rapidly than temperature, being remarkably greater therefore in liquids than in solids, and in airs than in liquids, the rate being quickened, moreover, near the points of change.*" (Read the Analysis, page 406.)

897. The following table, containing the names of some common substances, solid, liquid, and aëriform, shows, by the figures following each name, nearly how much the substance increases

in bulk, by having its temperature raised from that of freezing to that of boiling water. A lump of glass, for instance, would gain one cubic inch for every 416 cubic inches contained in it; while a mass of water would gain one inch for twenty-three, dilating thus for the same range of temperature eighteen times more than the glass.

SOLIDS.

Glass gains one part in	416
Deal	416
Steel	283
Iron	271
Brass	177
Silver	175
Lead	117

LIQUIDS.

Mercury gains one part in	55
Water	23
Fixed oils	12
Alcohol	9

AIRS.

Common air, and all gases and vapours	gain one part in about	3

898. We have to warn readers here not to confound the increase by heat of the general *bulk* of a solid body with the increase of its *length*. The latter is only one-third as great as the former. This will be understood by considering that the increase of bulk is made up of increase in the *length*, *breadth*, and *depth* (or *thickness*). If the substance of a metallic square rod or wire be dilated, by heat, a one-hundredth part of its bulk, it does not gain all that hundredth at its end, becoming 101 inches long instead of 100; but every part becomes deeper and broader in the same proportion as it becomes longer, and the rod gains in length only the third part of an inch. A fluid enclosed in a tube unchangeable by heat (if such tube there were) would show its whole dilatation in an increase of length, because there could be no swelling laterally, and its extremity, therefore, from any variation of temperature, would have a triple extent of motion. A degree of this consequence is obtained in our mercurial thermometers, because the containing glass, although dilatable by heat, is much less dilatable than the fluid within. As regards solids, we have to inquire so much more

frequently respecting only the dilatation in length or in breadth, or thickness, that is to say, the *linear dilatation* in one direction, than respecting the increase of general bulk, that tables are commonly made stating only the linear dilatation. And this may be found at once from the above table, by recollecting that it is one-third of the increase of bulk. Thus, as glass in passing from the freezing to the boiling heat of water, dilates one part in 416 of its bulk, it will dilate only one-third as much in length, namely, one 1248th part.

899. The expansion of solids by heat has been ascertained by bringing microscopic instruments to bear on marked rods of the different substances heated to various degrees in some liquid. The expansion of fluids, again, is found by filling a glass vessel with a known weight of a fluid, and then ascertaining how much is caused to run over or escape by a given increase of heat; or how much the fluid rises into a long tubular neck like the stalk of a thermometer. This quantity, when the required allowance is made for the expansion of the heated glass vessel (already known), declares the increase in the fluid itself.

The general and comparative expansion of solids by heat are exemplified in the following facts:

An iron bullet, when heated, cannot be made to enter an opening, through which when cold it passes readily.

900. A glass stopper sticking in the neck of a bottle, often may be released by surrounding the neck with a cloth taken out of warm water; or by immersing the bottle in the water up to the neck: or by making strong friction on the neck by a tape or any soft rope put round it, and then pulled backwards and forwards. By any one of these means the binding ring of the neck is heated and expanded sooner than the stopper, and so becomes for a short time somewhat more loose upon it. Tapping gently at the same time on the stopper with a piece of wood favours the operation.

Pipes of cast-iron for conveying hot water, steam, hot air, &c., if of considerable length, must have joinings which allow a certain degree of shortening and lengthening, otherwise a change of temperature may destroy them. An incompetent person who undertook to warm a large manufactory by steam from one boiler, laid a rigid main pipe along a passage, with lateral branches passing tightly through holes into the several apartments. On his first admitting the steam, the expansion of the main pipe made many fractures at the branches.

In an iron railing, a gate which during a cold day may be loose and easily shut or opened, in a warm day may stick, owing to there being greater expansion of it and of the neighbouring railing, than of the earth on which they are placed. The iron bars of railways are now formed with oblique surfaces at their meeting ends, to allow of expansion with changes of weather.

The iron pillars commonly used to support the front walls of houses of which the ground floors being meant to serve as shops have spacious windows, in warm weather really lift up the wall which rests upon them, and in cold weather allow it again to subside, considerably more than if the wall were of brick from top to bottom.

901. In some situations (as once was seen in the beautiful steeple of Bow Church, in London), where the stones of a building are held together by clamps or bars of iron driven into the stones, the expansion in summer of these clamps will force the stones apart sufficiently for dust or sandy particles to lodge between them: and then, on the return of winter, the stones not being at liberty to close as before, will cause the ends of the shortened clamps to be drawn out, and the effect increasing with every succeeding year, the structure may at last be dangerously loosened.

The pitch of a piano-forte or harp is lowered in a warm day or in a warm room, owing to the expansion of the strings being greater than that of the wooden frame-work; and in cold the reverse will happen. Thus an instrument, which has been well tuned in a morning drawing-room, may make discords when the crowded evening party has heated the room.

Bell-wires too slack in summer, may be of the proper length in winter.

902. One admirable contrivance for keeping the pendulum of a clock always of the same length, by making the greater expansion by heat of a middle bar of brass counteract the smaller expansion of two side-rods of steel, was explained under the head of "*Pendulum*," as was also the construction of a balance-wheel for watches having a corresponding property. A difference of a 100th of an inch in the length of a common pendulum causes a clock to err about ten seconds in twenty-four hours, and a rise or fall of 25° of Fahrenheit's thermometer may produce this difference. Another kind of compensating pendulum, not less admirable, distinguished by the name of its inventor *Graham*, is obtained by substituting for the solid bob or ball at

the bottom a glass vessel containing mercury. The mercury on expanding by heat, has its centre of gravity raised just enough to compensate for the lengthening of the pendulum-rod.

Thin strips of two metals differently expansible by heat, may be soldered together throughout their length to form one long straight riband. If this be then heated or cooled, it bends or curls like damp paper held before a fire. M. Breguet, of Paris, has constructed a very sensitive thermometer on this principle.

Crystals, when heated, do not expand quite equally in breadth and in length. The same is true of fibrous substances, as wood, which expands and contracts more in breadth than in length. This is instanced in the leaking during cold weather of a ship's deck, which in warm weather is tight;—an occurrence which the author, in rounding the Cape of Good Hope, had to regret as the cause of damage to some valuable specimens of natural history which he had collected among the Eastern Islands.

Bodies expanded by heat, unless when their intimate structure is changed by it, regain exactly their former dimensions on being cooled.

As is seen in the preceding table, the expansion of liquids by heat is much greater than of solids.

903. A cask quite filled with liquid in winter, must in summer force its plug, or burst: and a vessel which has been filled to the lip with warm liquid, will not be full when the liquid has cooled. It is thus that the mercury rises and falls in the stalk of a thermometer in proportion as that contained in the bulb is heated or cooled.

There exists, in the case of water, a singular exception already mentioned (Art. 508), to the law of expansion by heat and contraction by cold, producing unspeakable benefits in nature. Water contracts only down to the temperature 40°, while, from that to 32°, which is its freezing point, it again dilates.

Airs are expanded by heat still more than liquids.

904. The extent of this dilatation for airs is so much greater than for liquids or solids, that it forces itself much more strikingly upon the attention. Thus a bladder containing considerably less than its fill of air, becomes tense immediately on being held to the fire. The air in a balloon just escaping from a cloud, has been so suddenly expanded by the direct rays of the sun, as to injure the texture of the balloon. Some of the fatal accidents among aëronauts have been owing to this occurrence. Burning fuel passed into a vessel or case which can be suddenly

and strongly closed, will produce an expansion of the air confined within capable of bursting a vessel of ordinary strength—in short, may produce an explosion.

905. The expansion of aëriform bodies by heat produces many important effects in nature. Some of these have already been considered in preceding parts of this work, as, the rising of heated air in the atmosphere causing the winds all over the earth; the same in our fires and chimneys supporting combustion, and ventilating and purifying our houses; the same again from around animal bodies, removing the poisonous or contaminated air which issues from the lungs, and insuring a constant supply of fresh air for the support of life, &c.

The expansion by heat of air and other gaseous matter has lately become a subject of very high interest, from having led to new views in relation to the force not only of heat, but of whatever else is called force or energy in nature. This subject will be resumed after what has to be said on Latent Heat, in the section which follows the next.

"*The expansion of bodies by heat increases more rapidly than the temperature, and particularly near the melting and boiling points, that is, their points of changing into liquid or air.*" (Read Analysis, page 406.)

906. If a certain increase of temperature, accurately measured by any of the methods now practised, be given to a mass of cool water, it will produce in that a certain increment of bulk: and if other equal additions be afterwards successively made, each new one will produce a rather greater increment of bulk than the preceding, with diminished specific gravity, particularly when the water approaches to boiling. It is found, however, that after the water is converted into steam, or becomes aëriform, any farther increase of bulk is always closely proportioned to the increase of temperature. What is thus true of water in relation to heat is true of bodies generally, each, however, having a rate of expansion and temperatures for melting and boiling proper to itself. The quickened rate of expansion in solids and liquids might have been anticipated from reflecting that each successive quantity of heat added to a liquid, meets with less resistance to its expanding power than the preceding quantity, owing to the diminishing force of the mutual attraction of the particles as the mass enlarges; while in an air or gas, as such

cohesion has altogether ceased, each addition of heat is at liberty to produce a full effect. If the capacity of substances for heat did not increase with their bulk, the terms "increase in the amount of heat" and "increase of temperature" would have the same meaning, and this subject would be more simple.

907. The reflection may naturally occur here, that as in the common thermometer the mercury must rise or expand more for a given quantity of heat added at a high than at a low temperature, the scale should be divided to correspond with the inequality. This reasoning is good, but the difficulty of complying with it in practice is such, that the inconvenience of the slight error arising from an equal division is commonly submitted to. An air thermometer having equal divisions is more nearly correct, but from wanting many of the advantages of the mercurial thermometer, is little employed. The subject of unequal thermometric dilatation in the same liquid, and of the differences in that respect in different liquids, depending on the proximity to their boiling points, was well illustrated by Du Luc's experiment of charging several like thermometer-glasses, divided according to the scale of Reaumur, with different liquids, and while they were being heated through the same range of temperature, from zero or freezing (0°) to boiling (80°), noting their comparative indications. The discordance of the dilatations in different tubes when the instruments were placed together, and heated from the freezing (marked 0°, or zero, on Reaumur's scale) to the boiling degree of water (marked 80°), was as here detailed—

Mercury.	Alcohol.	Water.
0	0	0
10	7.9	0.2
20	16.5	4.1
30	25.6	11.2
40	35.1	20.5
50	45.3	32
60	56.2	45.8
70	67.8	62
80	80	80

The singular discrepancy in the case of water is owing to the peculiarity described in Art. 903 of its contracting by cold only down to 40° of Fahrenheit, and then dilating again until it freezes.

> "*To melt a solid body, or to vaporize a liquid, a large addition of heat enters it, but in the new arrangement of the particles and the generally increased volume of the mass, the heat becomes hidden from the thermometer and is called* LATENT HEAT. *It re-appears during the contrary changes, after whatever interval.*" (Read the Analysis, page 406.)

908. The expansion of bodies by heat, instead of proceeding throughout in a nearly uniform or gradual manner, makes in its course two great leaps, with singular transformations of the body: the first, when the solid breaks down into a liquid; the second, when the liquid swells out into an air or gas; so that there are in all, three very distinct modifications or stages of existence for the body dependent on the agency of heat. The substance of water, for instance, when at a low temperature, exists in the solid form called *ice;* but at 32° of Fahrenheit, on receiving more heat, it gradually becomes liquid or *water,* and on receiving still more heat at 212°, even under the resisting pressure of the atmosphere, it acquires a bulk nearly 2,000 times greater than it had as a liquid (gradually as regards the whole, but suddenly as regards each separate portion), being then called *steam* or aëriform water. And other bodies under analagous circumstances, undergo similar changes. It is further remarkable, that although during the changes a large quantity of heat enters the mass, producing in the one case the liquidity, in the other the form of air, the temperature or indication of the thermometer is the very same, immediately after, as immediately before the change, the heat received in the interval becoming hidden or latent in the mass:—thus water running from melting ice affects the thermometer just as the ice does, and steam over boiling water appears no hotter than the water. The glory of originally discovering the facts, to recall which, the terms *latent heat,* or *caloric of fluidity,* have since been used, belongs to the illustrious Dr. Black. The modern steam-engine was an early result of this discovery and of kindred investigations made by his friend, James Watt.

We select the following instances as serving to display the subject of *latent heat* in its various bearings.

909. A mass of ice brought into a warm room, and there receiving heat from every object around it, will soon reach the

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temperature of melting or 32°, but afterwards both the ice and the water formed from it will continue at that temperature until all be melted. The heat which continues to enter, effects a change only in the form not in the temperature of the mass. And whatever time was required for heating the mass of ice *one degree*, just one hundred and forty times as much will be required for melting it; proving that 140° is the latent heat of water.

If two similar flasks, one filled with ice at 32°, and the other with water at 32°, be placed in the same oven or over like flames, the water will gain 140 degrees of heat while the ice is merely being melted into water at 32°: and in the course of the experiment, a correspondence will always exist between the phenomena; for instance, when the water has gained 14° of heat, it will be found that just a tenth part of the ice is melted.

If equal quantities of hot and cold water be mixed together, the whole acquires a middle temperature, each degree lost by the hot water becoming a degree gained by the cold: but if a pound of broken ice at 32°, and a pound of water 140° hotter be mixed together, the 140° of heat will go merely to melt the ice, for there will result two pounds of water at 32°.

If a flask of water at 32° or its freezing point, and a similar flask of strong brine (which does not freeze until much colder) also at 32°, be exposed together in the same cold place, it will be found that when the brine has lost 10° of its heat the water flask will still exhibit an undiminished temperature, but a fourteenth part of its contents will be converted into ice. Now as in such a case the water flask must continue to radiate away heat just as much as the other, it can maintain its temperature only by absorbing into its general mass the heat which was latent in the portion of water frozen.

910. It is possible, by slowly cooling water which is kept in perfect repose, to lower its temperature, while yet liquid, ten degrees below its ordinary freezing point; but then, on the slightest agitation, ice will be formed. It might be expected in such a case, that the whole water would instantly freeze, because all of it is colder than common ice; but no, only a fourteenth part freezes, and singularly, both that fourteenth and the remaining liquid are rendered in the moment ten degrees warmer —rising to 32°. Here the 140° of latent heat escaping from the fourteenth part of the water which freezes, become 10° of sensible heat for the whole mass, so that the remaining water

has the temperature at which water in an open vessel begins to freeze.

Strong solutions in hot water of various neutral salts, if allowed to cool while exposed to atmospheric pressure, soon deposit crystals of the salts ; but in a close vessel which protects them from such pressure, they will remain liquid even when cold. Then at the moment of opening such a vessel to admit the pressure, the salt immediately crystallizes, and the latent heat given out by the solidifying particles warms very sensibly the remaining liquid and the vessel.

911. From the preceding facts it may be perceived, that the quantity of ice formed or melted in any case, becomes a correct measure of the quantity of heat transferred. From this consideration, the illustrious Lavoisier constructed his calorimeter, or heat-measure. It is a case or vessel charged with ice, and the quantity of heat given out by any body placed in it is indicated by the quantity of water collected from the melted ice.

Had the latent heat of water been only 1° or 2° instead of 140°, the earth, except in its tropical regions, would have been scarcely habitable by man. The cold of a single night might have frozen to the bottom the water of a deep lake, and the heat of a single day might have converted the accumulated snows of a winter into one sudden and most destructive inundation. As the fact is, however, both changes are beautifully gradual, and are easily controlled or prepared for.

The fact of latent heat in other liquids than water is familiarly exhibited in the *slow* melting of various substances, as—of the metals ; lead or pig-iron for instance—of butter or oils—of glass, &c.; and, on the other hand, in the slow solidification of any melted masses when heat is again withdrawn.

912. The substances below enumerated, while passing from the solid to the liquid state, absorb and render latent the quantities of heat here noted ; which quantities are therefore called the latent heats of the liquids.

Ice	140°
Mercury	142
Bees'-wax	175
Tin	500
Zinc	492

If a piece of frozen mercury (the temperature of which is at least 40° below zero) be thrown into a little water at 32°, the latent heat of the water immediately passes into the mercury and melts it; but singularly, the water in the act of melting the mercury is itself frozen.

913. Many substances, chiefly compounds of two or more elements, as wood, starch, wool, ivory, and various salts, are not melted by strong heat, but are decomposed.

914. It is a fact to be mentioned here that alloys or mixed metals are fusible at lower heats than the metals separately. Common solders are examples. An alloy consisting of eight parts of bismuth, five of lead, and three of tin, melts when thrown into boiling water. It is a kindred fact that in smelting metallic ores in furnaces, the mixture with them of certain other substances, as lime, facilitates the fusion.

"Latent heat of *aëriform fluids*."

915. Water in a vessel placed over a fire gradually attains the boiling temperature or 212°, but afterwards its temperature rises no more, because the further addition of heat becomes *latent* in the steam escaping during the ebullition. One way of determining the quantity of heat which becomes latent in steam is to note how much more time is required for boiling a quantity of water to dryness, than for merely heating it to the boiling point. The experiment indicates nearly 1,000 degrees; that is to say, nearly five and a half times as much heat becomes latent in any quantity of water formed into steam, as would raise the temperature of that quantity from freezing to boiling.

916. If we place in the same oven, or over similar flames, two like vessels containing water, one of which is open at top and the other is strongly closed, the two will gain heat equally up to the boiling point, but afterwards the open vessel, from giving out steam, will remain at the same temperature, while the other, by retaining all the heat which enters, will show the temperature continuing to rise, as before, until the increasing tendency of the water to dilate, forces the vessel open or bursts it. Supposing the water in the latter vessel, before vent is given, to have become 100° hotter than common boiling water, instead of the whole when set at liberty, being immediately converted into steam, as might be expected, only about a tenth part will be so changed,—the same quantity as will be found to have already escaped from the other vessel—for the tenth part requiring in the form of steam 1,000° of latent heat, will take the excess of 100° from the other nine parts, and will leave them in the state

of common boiling water. If, however, water heated considerably beyond the boiling point be allowed to expand *very suddenly*, the whole is blown out of the vessel as a mist, by the steam formed at the same instant through every part of the mass, but the whole mass in such a case is no more converted into steam, than the whole of a bottleful of very brisk *soda water* is converted into gas when similarly thrown out by the sudden extrication of the carbonic acid gas, on uncorking the bottle. Misconception of this matter has led to very wasteful experiments on steam-engines of unusually high pressure. It has been said that the water in such cases is "flashed into steam."

917. The same indication as to the latent heat of steam is obtained by the converse experiment of first converting a given quantity of water into steam, and then admitting it to cold water or to ice. A pound of steam so treated will raise the temperature of ten pounds of cold water 100 degrees, or will melt about seven pounds of ice.

In the great quantity of heat which becomes latent in steam, we perceive the reason why water projected upon a raging fire so powerfully represses it; and, again, why *fire* and *water* are so often associated proverbially as exemplifying a fierce antagonism.

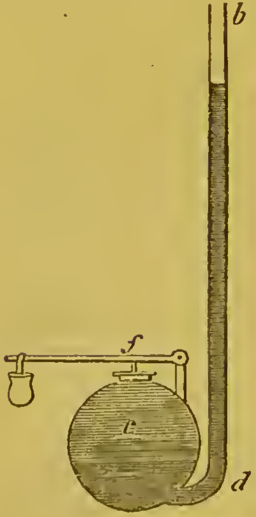
918. Substances differ among themselves in regard to the latent heat of their vapours as much as in their other relations to heat. Thus the latent heat of the vapour or steam of—

Water . . . . is nearly	1000°
Vinegar	900
Alcohol	370
Ether	164
Oil of turpentine	134

919. From the less abundant latent heat in these last-mentioned vapours than in that of water, one might at first suppose that there would be great advantage from using them in steam-engines. Accordingly, numerous experiments have been made, and patents secured, under this idea; but the fact is, that in the same proportion as the latent heat is less, the volume of the vapour is less, and therefore no mechanical advantage is obtainable.

The influence of external pressure in keeping the particles of water and other liquids together, in opposition to the repulsion of heat seeking to render their mass aëriform, was considered in the chapter on "*Pneumatics;*" but to render the present section complete, the subject is here shortly resumed.

920. Because water, or any liquid under the pressure of the atmosphere, while receiving heat, remains tranquil, and apparently unchanged, until it reaches what is called its boiling point, at which the bubbling or conversion into vapour takes place, we might deem that temperature necessary, under any circumstances, to enable it to assume or to maintain the form of air. But this is no more true than that a common spring compressed by any obstacle or force, has no tendency to expand until the moment when at last it overcomes the obstacle. Liquid water with heat to whatever amount is really a spring compressed by a weight of atmosphere, and seeking to expand itself into steam with force proportioned to its temperature. Even at 32°, or its freezing point, as is found by placing it in a vacuum, it assumes the form of air, with a force or pressure of 1½ ounce for every square inch of its surface, and is restrained from giving out more only by the counter-pressure of that which has escaped; and at any higher temperature, to correspond with the greater power of dilatation, the restraining force must also be greater: at 100°, for instance, it must be 13 ounces on the inch; at 150°, 4 lbs; at 212°, 15 lbs.; at 250°, 30 lbs.; and so on, as stated in Article 606. And when the restraining force is considerably weaker than the expansive tendency, the formation of steam takes place rapidly, not from the surface only, but also from within the substance of the liquid, so as to produce the bubbling and agitation called *boiling*. It is because the atmosphere or ocean of air which surrounds the earth happens to have in it 15 lbs. weight of air over every square inch of the earth's surface, and presses on all things there accordingly, that 212° has come to be called the boiling point of water. An atmosphere less heavy would have allowed liquids to expand into vapour at lower temperatures, and an atmosphere more heavy would have had a contrary effect.



The exact degree of expansive force for every degree of temperature in water and other liquids, has been ascertained in various ways; for instance, by heating them in vessels furnished either with fitly-loaded valves, as at *f* in this figure, or in vessels having from the bottom a tall upright tube, as *d b*, into which water in the upper part may force a column of mercury from below to an elevation, marking exactly the expansive tendency—the valve or the mercury being of course, for the time, protected from the external atmospheric pressure, or the necessary allowance being made for that pressure.

922. Boiling at the bottom of a deep vessel is resisted by the weight of liquid above, in addition to that of the atmosphere, as already explained, and consequently the temperature at which it occurs is higher than near the surface of the vessel. Boiling heat is greater also in deep mines, where, of course, there is additional depth and weight of atmosphere over any exposed liquid; it is so, too, when at any time the barometer is unusually high, that is to say, when the atmosphere is unusually heavy; in cases also where, by the containing vessel, air or steam is confined over a boiling surface so as to press strongly upon it, as when brewers for a time shut the lid or valve of their great boilers, &c. Water placed on the fire in a vessel from which steam cannot escape, may be rendered almost red-hot without a bubble forming or one particle being dissipated; but the tendency to expand into steam is then great enough to burst very strong vessels. The Marquis of Worcester exploded a cannon by shutting up water in it, and then surrounding it with fire. On the other hand, boiling temperature is lower on mountains, or in any situation above the level of the sea, where there is less height of air resting over the boiler. In the city of Mexico, which is on a table-land 7471 feet above the sea, water boils before it reaches the heat of 200°. A thermometer, when used for determining the height of mountains, balloon ascents, &c., merely by showing the heat of boiling water in any situation, is a good illustration of this truth. If in any place the atmospheric pressure is removed from a liquid, as by placing it in the receiver of an air-pump, it will boil at very low temperature indeed. Water thus treated boils at the heat of an English summer day; and ether boils when colder than common ice.

923. As water at any temperature is tending to dilate itself into steam, with force proportioned to the temperature, the temperature of the water in the boiler of a steam-engine tells the degree of force with which the steam is acting on the piston.

The same law holds for steam as for aëriform fluids generally, *viz.*, that the outward elasticity or spring increases in proportion as the fluid is more condensed. High-pressure steam, therefore, is merely condensed steam, just as high-pressure air is condensed air; and to obtain a double or triple pressure, there must be twice or thrice the quantity of steam under the same volume.

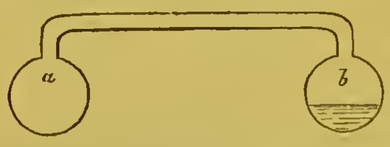
924. The reason that high-pressure steam issuing from a boiler heated to 300° or more, affects a thermometer only as low-pressure steam from a boiler at 212°, is, that in the instant when such steam escapes into the air, it expands until balanced by the pressure of the atmosphere, that is, until it becomes low-pressure steam, and it is cooled by the expansion, as air is cooled on escaping from any condensation. And further, in rushing against the thermometer, it carries much of the surrounding cold air with it.

925. The vessel called *Papin's Digester*, is a metallic pot or boiler, which can be kept closed by a regulating valve against the force of the steam formed within it; and in such a vessel water can be heated considerably beyond the ordinary boiling point,—sufficiently, for instance, to dissolve and extract all the gluten or jelly of bones immersed, and so to form from them a rich soup where ordinary boiling would get nothing.

The cook who increases the fire under a boiling pot with the hope of making the water hotter, is foolishly wasting the fuel, for the water can only boil, and it does boil at 212° of the thermometer.

926. As different substances, under any given pressure, become aëriform at different temperatures, mixtures of such may be decomposed by heat. If a mixture of alcohol and water, for instance, be placed over a fire, the alcohol will boil off long before the water; and if the vapour be directed into a cold tube or vessel, it takes the liquid condition, and the operation is called *Distillation.*

927. The little instrument here represented, called the *Cryophorus* (carrier of cold), illustrates well some of the principles above set forth. It consists of a bent glass tube blown into bulbs at the ends *a* and *b*, and hermetically sealed, after receiving into it some water, but no air. There will always be in the apparently empty part a steam or aëriform water of density depending on the temperature. If one of the bulbs be heated more than the other, the steam over water in that one will, for the reason stated above, be



denser and stronger than in the other, and will, therefore, be forcing its way into the other; where, owing to the lower temperature, a part of it will be constantly relapsing into the state of water, and making room for more. Hence, if the difference of temperature between the bulbs be long maintained, the whole water will, by a sort of distillation, gradually pass into the colder bulb. Two other remarkable facts which this instrument can exhibit are—1st, that if held with the tube nearly level, and undermost, the warmth of a hand grasping one bulb, will form steam, causing all the water to pass rapidly to the other, and to boil there; and 2nd, that by dipping one of the bulbs, nearly empty, into a freezing mixture, or by cooling it through the evaporation of ether from its external surface, the condensation of the steam within will bring back part of the water from the other bulb, and will cause the remainder left there to freeze or become ice.

928. When a liquid has reached the temperature at which it boils, that is to say, at which its power of emitting vapour becomes rather more than a balance to the atmospheric pressure, its dilating force is very strong. Persons may not reflect that 15 lbs. on a square inch, which is the atmospheric pressure, is 2160 lbs. on a square foot,—and such is the power with which the vapour of all boiling substances open to the air rises from them—sufficient in a large steam-engine to urge the piston with the force of 600 horses! But at temperatures far below boiling, the tendency to expand, as already stated, is still very great, and although not attracting common attention, is silently working most important ends in the economy of nature.—As into a perfect vacuum, freezing water, or even solid ice, gives out a steam or vapour which can lift an opposing weight with a force of 1½ ounce per inch, or 16 lbs. on a square foot, so also do many other liquids and solids. Thus, in the apparently empty space called the Torricellian vacuum, existing over the mercury in a barometer tube, there is always an aëriform mercury, more or less dense in proportion to the temperature; and around camphor, the essential or volatile oils, and other things, there is always an atmosphere of the substance, in the form of air, whether in otherwise empty space, or mixed with common air.

929. It had long been known that into space rendered a vacuum many bodies emitted quickly, in the form of gas, a quantity of their substance proportioned to their temperature; but it was but lately that Dalton made the important discovery that

into space containing air these vapours arise in quantity the same as if air were not present—the two fluids seeming to exist there independently of each other, with the exception, however, that in a vacuum the equable diffusion of a vapour takes place at once, while in a situation already occupied by air it proceeds more slowly, as the vapour has to force its way through the particles of the air, and it then takes place by a tranquil evaporation from the surface instead of by the agitation of ebullition. In an apartment with an open vessel of water in it, there is soon, although invisible, a steam, or watery vapour mingled with the air, as dense as if the room had been a vacuum at the same temperature.—Consequences of this important truth are the following:

930. That it is only an atmosphere of any volatile substance, which by pressing on the mass of it can prevent its further dissipation by heat. Thus camphor, musk, essential oils, spirits, water, &c., can be preserved only by placing them in closed bottles or vessels, in which, additionally to the air present, an atmosphere of their own substance is formed.

The important process of drying any moist object is merely the placing it under an elevated temperature if attainable, and in an atmosphere not containing so much moisture as to be saturated at the temperature. The effect of wind or motion of the air in quickening evaporation, is owing to its removing air saturated with the moisture, and substituting air which is not.

If air at a certain temperature contain mixed with it as much water as can be sustained in the form of invisible vapour at that temperature, and if then, by any cause, as rising in the atmosphere, the air be cooled, it will abstract heat from the vapour, and cause a portion to be precipitated or visibly condensed into a fog or rain. Water rising as invisible vapour from the surfaces of lakes or rivers, often, when it has reached a certain height and is cooled, condenses into the stratum of clouds which there appears, and which for a time may be usefully protecting the fields from the intense meridian sun, or may fall again as refreshing showers over the country.

It is the tranquil and invisible evaporation of which we are now speaking, which lifts from the surface of the globe all the water which, after condensation, returns to the ocean in the form of the myriads of river streams which give life and beauty to the face of nature.

931. There are other instances of vapour which is invisible while at a certain moderate temperature, but is copiously pre-

cipitated when the air with which it is mixed is cooled, or when it touches a colder solid body; such are—the steam observed at night and morning hovering over brooks and marshes heated by the sun during the day:—the frost-smoke, as it is called, which lies on the whole face of the Greenland seas in the beginning of winter, where the water, warmed by the long day of the polar summer, continues to emit its vapour for a considerable time after summer is past, into an atmosphere become too cold to preserve it invisible:—the breath or perspiration of animals, of horses in particular after strong exertion, becoming so strikingly visible in cold and damp weather, or even in warm weather, when the air is already charged with moisture:—in cities where there are deep drains communicating with kitchens, manufactories, &c., and constantly filled with moist and warm air; the vapour-loaded air, although clear or transparent in the drain, immediately on escaping into a frosty atmosphere, lets go its moisture, with the appearance of steam issuing from a great subterranean cauldron. Steam over water in any boiler is transparent or perfectly aëriform—as may be seen when water is made to boil in a vessel of glass; but as soon as it is cooled, by contact or admixture of colder air, it ceases to be true steam, and is condensed into small particles of water suspended in the air. Many persons, while thinking of steam, figure it only in this last-mentioned condition, of particles of water mixed with air nearly as a subtle powder might be mixed. Until steam is cooled and condensed, it is of a nature to fill alone any appropriate vessel and powerfully to distend it, just as air fills and distends a bladder. Steam issuing from the spout of a tea-kettle is hardly seen near the mouth, but as its distance from the spout increases, it is cooled into a jet of thick cloud or vapour.

932. In a vessel from which air and therefore atmospheric pressure are excluded, even the temperature of freezing water is sufficient to maintain permanently in the state of invisible gas many substances which exist as liquids under the atmospheric pressure. And a large mass of any such substance when placed in a vacuum, is not instantly converted into gas, because the portion which first rises becomes an atmosphere compressing what remains, and because, moreover, that portion, by absorbing from the mass much heat into the latent state, cools the mass very much. We see, therefore, why liquids are so rapidly cooled when placed wherever a vacuum can be made and maintained; that is to say,

where, after common air has been removed, the aëriform matter rising from the liquid and absorbing its sensible heat, is also promptly and in a continued manner abstracted. It is thus that water placed in the exhausted receiver of an air-pump is so rapidly cooled, and that when there is placed beside it a vessel of concentrated sulphuric acid, or other substance capable of absorbing the watery vapour as formed, it is soon reduced to the state of ice; or again, that water, or even mercury, in a cup surrounded by ether evaporating in a vacuum, is so quickly frozen. This is further explanation of the experiment described in Art. 927.

933. As it has been explained now, that in a liquid there is the same tendency to evaporate whether it be or be not exposed to the air, we see the reason why all evaporation is a very cooling process. The effect, however, in air is neither so rapid nor so great as in a vacuum, first, because the presence of the air impedes the spreading of the newly-formed vapour from the liquid surface, and keeps it where its pressure resists the formation of more vapour; and, secondly, because the air in contact with the liquid, gives part of its heat to the liquid. Still in India, flat dishes of water, placed during the night on beds of twigs and straw kept wet, and in a current of air, soon exhibit thin cakes of ice on the surface.

The absorption of latent heat in the evaporation which goes on from the sea and earth in all warm climates, greatly tempers the heat of these climates; and the vapour afterwards spreading to the poles, as explained in "*Pneumatics*," under the head of *Winds*, carries warmth thither to be given out as it is recondensed into the form of rain, or is solidified as snow. The formation anywhere of mist or rain warms the supporting air, by the liberation of the latent heat from the precipitated vapour. Again, the water which during winter is converted into snow or ice, had been a reservoir of latent heat given out to temper the frosty air of the cold season; and in the following spring, such ice and snow may serve as receptacles in which the first violence of the returning sun may hide or expend itself. The vast stores of ice and snow among high mountains, as among the Alps and Pyrenees, serve often during the summer as stores of mild temperature to regions around: for, besides cooling the air near them, they are the never-failing sources of the cool rivers which run from them during the whole of summer, carrying freshness throughout distant lands.

934. Persons in artificially raising temperature, are generally causing the liberation of heat which had been previously latent; and in lowering temperature or producing cold, they are generally rendering a quantity of heat latent which had previously been free.

The theory of Lavoisier, which for a time prevailed, was that the heat of all combustion was merely the latent heat of the oxygen gas concerned in the combustion, given out during its combination with the burning body. This is true in part, but we know now that much also depends on the intensity of the chemical action which takes place between the combining substances. Water thrown upon quicklime to slake it, becomes solid in combination with the lime, and gives out its latent heat.

935. When dwelling-houses, green-houses, manufactories, &c., are warmed, as is now common, by the admission of steam into systems of pipes which branch over them, the heat is that which was previously latent in the steam, and which spreads around as soon as the steam, by touching pipes of lower temperature, is condensed to a state of water.

Again, for producing cold artificially, the processes generally involve the conversion either of a solid into a liquid, during which it takes and hides in its new constitution as latent heat much of the heat previously sensible in it, and in the liquid which dissolves it; or of a liquid into vapour, during which heat equally becomes latent. Thus by dissolving a salt—nitre, for instance—in water, we obtain a solution which is very cold. In India a common mode of cooling wine for table is to surround the bottles with nitre thus melting; and the water of the solution being evaporated again before next day, the salt is left ready for use as before.

936. Such is the mutual attraction of water and many salts, that they readily combine, assuming the liquid form, even when the water is used in the solid state of ice; and, as in that case, both the water and the salt render heat latent, the fall of temperature is doubly great. Thus, common salt at 50° and snow (or ice) at 32°, when mixed, dissolve into liquid brine 37° colder than freezing water, or 5° below the zero of Fahrenheit.—This action of salt on ice leads to the common practice of sprinkling salt on an ice-covered pavement before a street door to clear away the ice. The salt and ice quickly combine and form liquid brine, which either of itself runs off into the gutter and

disappears, or is easily swept off. It is true that the brine is at first a powerfully refrigerating mixture, which cools still more the pavement and the neighbouring ice.

The following is a short table of easily procured freezing mixtures:—

937. *Frigorific Mixtures.*

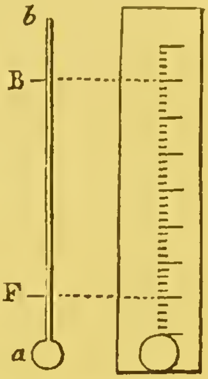
Substances mixed.		Thermometer sinks.
Common salt	1 part	From temperature of 50° above to 5° below zero.
Snow, or pounded ice . . .	2 parts	
Common salt	5 ,,	From temperature of 50° above to 25° below zero.
Snow or ice	12 ,,	
Nitrate of ammonia . . .	5 ,,	
Snow	3 ,,	From 20° below to 60° below zero.
Diluted sulphuric acid . .	2 ,,	
Nitrate of potash	4 ,,	From 50° above to 4° above zero.
Water	3 ,,	
Sulphate of soda	8 ,,	From 50° above to 0° or zero.
Muriatic acid	5 ,,	

> "*For any given substance, the changes of state from solid to liquid, and from liquid to air, happen, under similar circumstances, so precisely at the same temperature, that they mark fixed points in a general scale of temperature, and enable us to regulate and compare our various thermometers.*" (See Analysis, page 406.)

938. As we can neither weigh heat, nor measure its bulk, nor see it, and as, even if our sense of touch were a correct judge in the matter, which it is not, we dare not touch things that are very hot or cold, some other expedient was wanted for estimating the presence in bodies of this very subtle something; and that has been found in the measuring of its most obvious and constant effect, namely, that dilatation or expansion of bodies when heated which again ceases when the heat is withdrawn. Any substance so circumstanced as to allow this expansion to be accurately measured, becomes to us a *thermometer* or *measure of heat.*

939. In *solid* substances, the direct expansion by heat is so small as to be seen or measured with difficulty. In *air*, again, the expansion is very great: but there is the objection that in any apparatus yet contrived, which will allow that completely to appear, the air cannot be protected from the varying pressure of the atmosphere—an influence which affects its volume as

much as changes of temperature. *Liquids,* however, are free from both disadvantages, and when a small quantity is placed in a glass bulb, as *a*, having a long neck or stalk *a b*, into which it may rise to be measured, when expanded by heat, they form the most generally convenient kind of thermometer. Then, among liquids, mercury is, on several accounts, peculiarly suitable. In it, the range of temperature, between its freezing and boiling, is greater than in any other liquid, and it reaches a lower point than any except alcohol, or ether; its little capacity for heat, and ready conducting power, cause it to be very quickly affected by change of temperature; its expansion is singularly equable for equal increase of heat through the important middle part of the scale, which includes the common temperatures on earth, namely, from the freezing to the boiling heat of water; and it is easy to proportion the bulb and the stalk to each other, so that a small difference of temperature shall cause the mercurial column in the stalk to rise or fall very conspicuously.



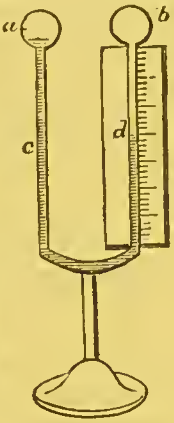
940. Now when the important fact was ascertained that solid water or ice melts everywhere at precisely the same temperature, and that pure liquid water in a metallic vessel, and under a given atmospheric pressure, boils always at the same temperature, it followed that by placing such a thermometer as above described, first in melting ice, and then in boiling water, and marking upon the stalk the two points at which the mercury stands, as represented here by F and B, two fixed or invariable points of reference are obtained, and the interval between them can be divided on the glass, or on a suitable scale attached to the glass, into any convenient number of parts to be called degrees. It follows farther, that by continuing the divisions to any extent both above and below the fixed points, a general scale of temperature would be obtained, with respect to which all thermometers made on the same principle would perfectly agree, although the size of the divisions on the stalks would vary in the different instruments according to the comparative capacities of the bulb and stalk. Newton had the honour first to propose as points of comparison, the points of freezing and boiling water, and these are now universally adopted. The interval between them, however, has been variously subdivided —that is to say, there has not been agreement as to what would

be conveniently called a degree of heat. In the Centigrade thermometer, which is the most simple, and, doubtless, will at last be generally used, the division is into 100 equal parts: in Reaumur's, long employed in France, it is into 80 parts; and in Fahrenheit's, still commonly used in England, and, therefore, referred to in this book, it is into 180°. In Fahrenheit's, moreover, the freezing point, instead of being called *zero,* as is more suitable, is called 32°, because the maker happened to begin counting from the lowest heat which he met in Iceland, and which was 32 of his degrees below the freezing point of water. To turn the degrees of any one of these thermometers into degrees of any other, we have only to recollect that 9° of Fahrenheit are equal to 5° of the Centigrade, and to 4° of Reaumur. Therefore, according to the common rule of three, multiplying by 9 and dividing by 5 or 4, or the reverse, and adding or subtracting the 32° of Fahrenheit when required, gives the result desired. (See the Appendix.)

941. The bulb of a mercurial thermometer is formed by heating to softness, in the flame of a lamp, the end of a glass tube, which has a very small and equable bore, and then blowing into the tube until the softened end swells like a soap-bubble to the size desired. The mercury is forced into such a bulb through the long stalk by the pressure of the atmosphere, thus: First, a portion of the air originally in the bulb being expelled by warming the bulb, the open end of the stalk is immersed in mercury, and when the air remaining in the bulb cools and contracts, a little mercury is pressed in by the atmosphere. Secondly, this admitted mercury having been made to boil, so as to fill with its vapour the whole capacity of the bulb and tube, and thereby to expel all air, on the open end being again immersed in mercury, and the mercurial vapour within being condensed by cold, the atmosphere presses in fresh mercury to fill the whole. To complete the operation, the bulb is again heated to expel so much of the mercury as that when cold the tube shall be about one-third full of it, and then, before the heated mercury begins to recede, the end or opening of the tube is hermetically closed by directing upon it the point of a blowpipe flame, which fuses the glass.

Although the *direct* expansion of any solid body by a moderate change of temperature is so inconsiderable as to be with difficulty measured, M. Breguet, of Paris, ingeniously contrived a solid thermometer which makes it very evident. (Article 902.)

942. Air is a substance on several accounts well adapted to the formation of a thermometer; for it has great extent of dilatation from small increase of heat; it quickly receives impression, and its dilatation is equal for equal increments of heat at all temperatures:—but, as already stated, there is the strong objection that the pressure of the atmosphere cannot be excluded, without at the same time confining the air, and affecting its expansion. Professor Leslie, however, devised for particular purposes an air-thermometer, which he employed very usefully, calling it the differential thermometer. It consists of two bulbs *a* and *b*, filled with air, and connected by a bent tube *d c*, containing liquid—the instrument being hermetically sealed, so that the atmosphere cannot affect the air within. Greater heat in the bulb *b* than in the other, as when that bulb is touched by the warm hand or is exposed to the sun's ray, is marked by the descending of the liquid in the tube *d*, which has a graduated scale attached to it. We may observe that equal divisions or degrees marked on the scale of this thermometer do not mark equal changes of temperature, for the increasing condensation and resistance of the air in the colder bulb, and the increasing height of the liquid column to be lifted, require the force overcoming these progressively to increase.



943. *Maximum* and *Minimum Thermometers.*—It is often desirable, as in garden hot-houses, to know how low the temperature has fallen during the night when no observer was present, and how high it has risen in the day. Both ends are attained by the use of Rutherford's twin-thermometers with horizontal tubes. The mercury in the tube of one pushes forward, as it advances with heat, a small piece of iron wire, and leaves it as a marker unmoved when it recedes again. The spirit or alcohol in the other, when contracting with cold, draws after it, by the mutual attraction, a small piece of glass as the marker, and then flows past that without moving it when expanding again with heat.

Temperatures below that of freezing mercury are usually measured by a thermometric tube containing alcohol; and temperatures higher than that of boiling mercury are measured by the expansion of air or of metals, as above described, or by the contraction of pieces of baked clay, which when highly heated lose water and contract in bulk. The use of baked clay was proposed by Wedgwood, and the apparatus has been called Wedgwood's *Pyrometer*, or fire-measure. Contrivances for measuring intense heat may be graduated so as to agree more or less accurately with the scale adopted for the mercurial thermometer.

It is very interesting, while considering the vast number and importance of the phenomena produced by heat, to observe the degrees in the general scale of temperature at which changes take place. In the following table a selection of the facts are classified, the temperatures being referred all to the scale of Fahrenheit s thermometer.

944. *Table of facts connected with the influence of heat corresponding to certain temperatures.*

	Wedgwood.	Fahrenheit.
Highest temperature measured	240°	32,277°
Chinese porcelain softened	156	21,357
Cast iron thoroughly melted	150	20,577
Greatest heat of a common smith's forge	125	17,327
Flint glass furnace	114	15,897
Stoneware baked in	102	14,337
Welding heat of iron	90 to 95	13,427
Delft ware baked in	41	6,407
Platinum melts at		3,080
Fine gold melts	32	2,282
Settling heat of flint glass	29	2,000
Fine silver melts	28	1,832
Brass melts	21	1,650
Full red heat (*the beginning of Wedgwood's Pyrometer*	0	1,077
Heat of a common fire		790
Iron red in the dark		750
Quicksilver boils		660
Linseed oil boils		600
Lead melts		594
Sulphur melts		226
Water boils		212
A compound of three parts of tin, five of lead, and eight of bismuth, melts		210
Alcohol boils		174
Bees'-wax melts		142
Ether boils		98
The present medium temperature of the globe		50
Water freezes		32
Milk freezes		30
Vinegar freezes		28

		Fahrenheit.
Strong wine freezes		20
Weak brine freezes	*zero*	0
Quicksilver freezes	*below zero*	40
The air sometimes at Hudson's Bay	*below zero*	50

There is reason for thinking that the higher temperatures noted in this table are considerably too high, owing to the insufficiency of the thermometer or pyrometer (Wedgwood's) by which they were estimated.

From what is said in the last and in preceding paragraphs, it is evident that the thermometer gives very limited information with respect to heat: it merely indicates, in fact, what may be called the tension of heat in bodies, or the tendency of the heat to spread from them. Thus it does not discover that a pound of water takes thirty times as much heat to raise its temperature one degree as a pound of mercury; nor does it discover the heat of fluidity absorbed when bodies change their form, and which is called "latent heat" only because hidden from the thermometer.

> "*Heat by its different relation to different substances has a powerful influence on their chemical combinations.*" (Read again the Analysis, page 406.)

945. By observations made and recorded through past ages, man has now come to know that the substances constituting the world around him, although appearing to differ in their nature almost to infinity, are yet all made up of a few simple elements variously combined; and he has discovered that the peculiar relations of these elements to heat, particularly their being unequally expanded by it, and their undergoing fusion and vaporization at different temperatures, furnish him with ready means of separating, combining, and new-modifying them to serve to him purposes of highest utility. Where the primitive savage, looking around on rocks and soils, saw in their diversified aspect almost as little meaning as did the inferior animals which participated with him the shelter of the forest or cave, his descendant, with penetration sharpened by science, descries at once the treasures of the mine, and aided by heat, whose wonderful energies he has learned to control, pursues through all the Protean disguises of ores and salts and solutions, each of the wished-for substances, until he secures it apart. For instance, in what to his forefathers for thousands of years

appeared but a red dross, he knows that there lies concealed the precious iron—king of metals! and soon forcing this in his glowing furnace to assume its metallic form, he afterwards, with implements made of it, moulds all other bodies to his will: the trees from the forest and the rocks from the quarry, in obedience to his tools of iron, are fashioned by him as if they were of soft clay, and at his command rise into the magnificent structures of palaces and ships, with which the earth and the ocean are now covered. The minute details of the relations to heat of particular substances belong to that department of science called *chemistry* (a name taken from an Arabic word signifying *fire*); but a few general remarks on the subject are appropriate in the present work.

946. The most common ores of metals are combinations of the metals with oxygen, carbonic acid, or sulphur—substances all of which are volatilized at much lower temperatures than the metals. Now simple roasting, as it is called, or strongly heating the ores, suffices often to drive away great part of these adjuncts; and where additional assistance is required, it is obtained by mixing with the ore something which when heated attracts the substance to be expelled more strongly than the metal does. Charcoal, for instance, heated with an oxid-ore, takes the oxygen, and flying off with it as aëriform carbonic acid, leaves at the bottom of the furnace or crucible the vivified or pure metal.

947. Mercury, which is a metal having at common temperatures the liquid or melted state, when mixed with the dross of a mine, dissolves the particles of gold or of silver therein existing, and the ingredients of the solution are afterwards obtained apart by mere heating—the mercury passing away as vapour to where it is cooled, and thereby condensed and recovered for subsequent use, while the more fixed gold or silver remains in the vessel. In this as in all other distillations, such as that of spirit from wine, or of essential oils from water, &c., there is the separation by heat of a more volatile from a less volatile substance. The only difference between what is called drying by heat and distilling is, that in the one case the substance vaporized, being useless, is allowed to escape or become dissipated in the atmosphere; while in the other, being the precious part, it is caught and condensed into the liquid form.

948. A piece of cold charcoal lies in the air for any length of time without change: but if heated to a certain degree, the

mutual cohesion of its particles is so weakened, in other words, the particles are by the heat so repelled and separated from one another, that their attraction for the oxygen in the air around is allowed to operate, and they combine with that oxygen, exhibiting during the union the phenomenon of combustion. The same is true, under similar circumstances, of almost any dry vegetable or animal substances, and of several of the metals.

949. Nitre, sulphur, and charcoal, while cold, may be mixed together most intimately in any proportions without change taking place; but if the mixture be in certain proportions, and if then any part of it be heated to a certain degree, the whole explodes with extreme violence—for it is gunpowder. By the change of temperature, and the consequently altered relative attractions of the different substances, a new chemical arrangement of these supervenes with the intense combustion and expansion, which constitute the explosion.

950. Sea-sand and soda again, although very intimately mixed, and even ground together, if remaining cold, remain also merely an opaque and useless powder: but if the mixture be heated, to diminish the cohesion of the particles of each substance to those of its own kind, while the mutual attraction of the different substances may come into play, these substances melt together, and unite chemically into the beautiful compound called glass; a product, than which human art has formed none more admirable.

951. Perhaps the influence of temperature on chemical union is nowhere more remarkably exhibited than in retarding or in hastening the decompositions of dead vegetable and animal substances. The functions of life bring into combination, to form the various textures of organic or living bodies, chiefly five substances, *viz.*, *carbon* or coal; *lime;* the ingredients of water, namely, *oxygen* and *hydrogen;* and, lastly, *nitrogen*—which substances, when in the proportions found in such bodies, have but slight attraction for each other, and all of which, except the *carbon* and *lime*, usually exist as airs. Their connexion, therefore, is easily subverted; and particularly by a slight change of temperature, which either so weakens their mutual hold of one another as to allow new arrangements to be formed, or altogether disengages the more volatile of them.—At a certain temperature, a solution of sugar, for instance—which consists of three of the substances, carbon, oxygen, and hydrogen—undergoes a change into a spirituous wash, from which spirit or

alcohol may then be obtained by distillation; but if the heat be continued under certain circumstances, the liquid undergoes a second change, or forms a new arrangement of the constituent particles, constituting vinegar: under still other circumstances it undergoes a third change, which is a destructive decomposition, and the oxygen and hydrogen, with carbon dissolved, ascend away as airs. But sugar, and many similar vegetable compounds, as the pitch of Egyptian mummies, if kept at a low temperature, remain unchanged for ages.

952. Then, as regards dead animal substances, we find that although at a certain, not very elevated, temperature, they quickly undergo the change in the relations of their elements called putrefaction, during which nearly their whole substance rises again in form of gas to become part of the atmosphere, still at or below the temperature of freezing water, they remain unaltered for any length of time. In the middle of summer, recently caught salmon packed in boxes with ice, is conveyed fresh from the most remote parts of Britain to the capital. During the warmest weather, flesh of any kind may long be preserved in an ice-house. In Russia, Canada, and other northern countries, on the setting in of the winter frosts, when food for the cattle and poultry is with difficulty procured, the inhabitants kill their winter supply, and store up their frozen provender as in other countries men store what is salted or otherwise preserved.

953. A more striking illustration of this subject cannot be adduced than the fact that, in 1801, on the shore of Siberia, in a vast mass of ice, then accidentally broken and partially melted, the carcase of what has been called the antediluvian elephant was found, perfectly preserved—an elephant differing in many respects from those now existing on the earth, but having a skeleton exactly similar to the fossil specimens found deeply buried in many countries. The carcase was soon discovered by the hungry bears of the district, which were seen eagerly feeding on its flesh, as if it had died but yesterday, although it must have been of an era long antecedent to human records. After it had fallen from the ice to the sandy beach, and its tusks had been carried away for sale by a Tungusian fisherman, and much of its flesh had been devoured, a naturalist from St. Petersburgh who visited it found an ear still perfect, and its long mane, and part of its upper lip, and an eye with the pupil, which had opened on the scenes of a younger world! About 30 lbs. weight of its hair, which had been trodden into

the sand by the bears, and part of the skin, were preserved, and are now distributed in different museums of natural curiosities. A piece of the skin with the hair upon it is to be seen in the museum of the London College of Surgeons.

"*Heat has powerful influence also on animated nature, both vegetable and animal.*" (Read the Analysis, page 406.)

954. If it may be said that heat communicated to the boiler of a steam-engine is the cause of all its succeeding motions—the heaving of its beam and pumps, the opening and shutting of its valves, the turning of its wheels, and its ultimate performance of any work like spinning, or weaving, or grinding, or propelling vehicles by land and water—as truly may it be said that heat coming to a seed which has long lain unchanged during the cold of winter, is the cause of the commencing germination; and afterwards, of its growth, the rising of its sap, the new budding and unfolding of its leaves and blossoms, the ripening of its fruits, with the production of new seeds to perpetuate its kind. Then, in the still more complex organisations and functions of the animal kingdom, the agency of heat is equally essential. By heat an egg, which, if cold, would lie motionless until it rotted, is soon converted into a living being, which in favourable circumstances gradually attains maturity, with form and faculties marvellous indeed. Great reduction of temperature occurring anywhere extinguishes life.

955. Besides the effects of heat above spoken of, which are periodical and comparatively transient, as being connected with the seasons, there are other effects on animated nature of a more permanent character. Different species of vegetables and animals, by their relation to heat, are confined to certain latitudes or climates; and when the individuals of any class become habituated to a climate differing from that in which their progenitors lived, they acquire new characteristics dependent on the climate, as seen in the sheep and dogs of the various regions of the earth. In this respect there is no instance more striking than that furnished by the varieties of the human race.

"*The great natural source of heat to this earth is the sun.*" (Read the Analysis, page 406.)

956. Many of the facts set forth in the preceding sections are direct proofs of this truth. No wonder, then, that through

antiquity many ignorant or savage nations, seeking the source of their life and happiness, looked to the sun not only with feelings of admiration but of worship.

957. The heat comes from the sun with his light. If a sunbeam enter, by an opening made in the window shutter, an apartment previously closed and dark, it illumines instantly and intensely the spot or object on which it falls, and its light being then scattered around, all the objects in the room become visible. Again, if a cold thermometer be placed to receive such direct rays, it rises much, and gradually objects around will be affected. Light passes from the sun to the earth in about eight minutes of time, as will be explained under astronomy, and there is proof that the heat travels at the same rate.

958. Human art can now, by concave mirrors or convex lenses, gather the sunbeams together, so as to produce intense heat in the focus of their meeting. A surface of glass, or any other small mirror, will reflect the sun's rays so as strongly to affect the eye at a distance even of miles; and that the heat accompanies the light is shown by the fact that many mirrors directed towards one point heat intensely. Archimedes is said to have set fire to Roman ships besieging Syracuse by sun-beams thus returned from many points to one. When the light of a very broad sunbeam is made by a convex glass or lens to converge accurately to one narrow focus, the concentrated heat is sufficient to cause a piece of metal held in the focus to drop like melting wax. Persons wherever the sun can be seen may conveniently light their fires at the sun by directing his energies through a burning glass.

959. Reflection on such facts as now referred to, and on the globular form and changing positions in relation to the sun of our earth, gives clear explanation and measure of the differences of climate and of season found in different parts of the earth. All understand that if a small globe be suspended before a fire, the part which is nearest to the fire and receives the rays directly, will be much more heated than the other parts receiving the rays more or less obliquely. So on this earth, which is rotating before the sun, the regions about the equator are the most heated. The sunny side of many a steep hill in England receives the sun's rays in summer as perpendicularly as the plains about the equator; but such hill-sides are not heated like those plains, because the air over them is colder —as very elevated mountain tops, even at the equator, owing to

the rarified, and, therefore, cold air always around them, remain permanently hooded in snow. In England, at the time of the equinoxes, a level plain receives only about half as much of the sun's light and heat as an equal extent of level surface near the equator; and in the short days of winter, when the beams fall more obliquely, it receives less than a third part of the summer amount.

960. A picture has been designed to aid a student in conceiving clearly the consequences of the different intensities of the sun's influence in different latitudes on earth. It is an elongated landscape of a strip of the earth's surface, stretching from the equator to the pole, exhibiting the more remarkable objects belonging to the vegetable and animal kingdoms peculiar to the different latitudes. At the equatorial end of this representation appear, amidst the endless variety of broad-leaved palms, such animals as the elephant, tiger, parrot, etc., and men as naked savages, or as the civilized Hindoos, seeking the shade of bungalows with darkened windows, and wetted mats hung round the walls to cool them. Corresponding views are given of the intermediate temperate climates, until at the polar extremity appear the dwellers in barren Greenland or Iceland, where the thermometer stands below zero, and the people are clothed in thick furs of polar animals, and protected by close artificially-warmed houses. Then one reflects that all the contrasts here referred to are in existence at the same moment of time. A person has actual experience of such a contrast who, as happened to the present writer, sails rapidly from a warm and rich garden like the country around Rio de Janeiro, in Brazil, to Tristan da Cunha, or the Isle of Desolation, in the Southern Ocean, where the surface is bare rock, but yet where the scene swarms with appropriate forms of life. In the sea appears the whale, on the rocky coasts the seal, and in the air are clouds of the white feathered sea-fowls playing over the ever-moving waves like flakes of eddying snow.

961. An interesting evidence of solar influence on our globe is the periodical migration of animals which have their home not in any fixed region on earth, but wherever the sun has for the time the particular degree of influence best suiting them, and which accordingly follow the sun in the changes of season. In England, for instance, we have the swallow in vast numbers coming to visit our isles in the spring, to play over our woods and waters in pursuit of the insects which the heat then

breeds to fill the air; and in autumn the same creatures are seen congregating on the shores, to wing their flight back in united multitudes to more southern countries, where, in turn, they find the needed warmth. The same season brings the cuckoo, the nightingale, and many other winged species. In the waters of the bays and coasts, too, there appear in their seasons vast shoals of the finny races—the herring, the mackerel, and the beautiful salmon, which last, at stated times, penetrates from the ocean far up the mountain streams, to deposit its spawn in suitable localities.

> "*Man, by arts of his invention, through* Combustion, Friction, Electricity, *&c., can produce heat at will, and has thereby gradually acquired complete control for his purposes over many of the occurrences in the world around him.*" (Read the Analysis, page 406.)

Combustion.

962. Of the phenomena of nature over which man has now acquired power, no one, when first observed, could excite more wonder and terror than *fire* or *combustion.* It might be seen spreading in a mass of any combustible matter after an accidental lightning-stroke, or when like matter were reached by a stream of red-hot lava issuing from a volcano. And great indeed must have been the surprise of a spectator who first witnessed the bursting into flame of two pieces of dry wood, strongly rubbed against each other. Such rubbing is the mode of lighting a fire still practised among rude or savage people. Little could any one have then anticipated what has now come to pass: that the dread agent would in time, by human ingenuity, be rendered the most obedient and useful assistant to man in all the labours of a coming high civilization. Now under the domestic roof fire is preparing wholesome food for the people; in laboratories it is separating metals from their ores, or melting together the sand and other ingredients which form glass or like useful compounds; and, to say much in few words, fire actuating the steam-engine, is performing most perfectly nearly all the kinds of mechanical work which human hands did in former times, and many kinds of labour which, owing to their magnitude, the strength of men had never attempted.

963. Singularly interesting, then, to philosophers, as in various uses the phenomenon of combustion must always have appeared, one might have expected that its true nature would not long be to them a mystery; but until the noble discoveries and reasonings of such men as Priestley, Lavoisier, Davy, and others, made not yet a century ago, the conjectures offered on the subject had scarcely approached the truth. The common opinion was that in every combustible substance there was present in close combination, a certain quantity of a something denominated *phlogiston*, which on being disengaged or separated, became obvious to human sense as light and heat. For instance, the white oxide of zinc, called the flowers of zinc, into which the metal is changed by burning, was supposed to be the metal deprived of its phlogiston; and when, on this oxide being again heated in mixture with charcoal, the metal reappeared, it was supposed simply to have recovered phlogiston from the charcoal. The illustrious Lavoisier had the merit of clearly disproving this hypothesis, by showing that the flowers or powders obtained from metals by burning were heavier than the pieces of metal from which they were produced, and by the exact weight of the oxygen gas which disappeared in the combustion; and he showed further, that in this and many other cases, combustion was merely the act of substances having strong affinity or attraction for one another combining chemically; but he fell into an error of another kind by supposing that to produce any combustion oxygen had always to be one of the combining substances, and that the heat and light given out had in every case been previously latent in the oxygen.

964. When Sir Humphry Davy began his labours on this subject, than which labours there are, perhaps, on record few such interesting examples of scientific research, the existence and nature of oxygen had already been discovered by Priestley, the facts of latent heat by Black, and the important facts already referred to by Lavoisier. It was known also that bodies, when compressed or by other means reduced in bulk, generally give out a part of their heat, as when air condensed under the piston of the match-syringe lights tinder attached to the bottom of the piston, or when water and sulphuric acid uniting into a compound of smaller volume than the separate ingredients, become very hot, or when water poured upon quicklime to slake it, and becoming solid with it, produces strong heat, and that in such cases the heat produced during the chemical union seemed to

depend more upon the energy of the action which united the substances than upon the change of volume produced.

Farther, it was known that any substance having its temperature raised, by whatever means, to 800° or more of Fahrenheit's thermometer, became incandescent or luminous, as when iron, or stone, or any other substance which is not dissipated by heat, is placed in a common fire—the substance heated in a lower degree being said to be red-hot, and at higher temperatures to be white-hot.

965. Out of these and other facts Davy drew satisfactory explanations. He concluded, first, that, in any case, combustion is merely the appearance produced when substances having a still stronger attraction for each other than quicklime and water, for instance, are, with intense energy, combining chemically, so as to become heated to at least the degree of incandescence; and that during the phenomenon there is not, as was formerly supposed, something altogether consumed or destroyed, or something called *phlogiston* escaping, but that the substances concerned are only assuming a new form or arrangement of particles combining in perfect union. Thus, if a piece of charcoal be enclosed in a glass vessel filled with atmospheric air, of which vessel the mouth dips into a liquid to confine the air, and if the charcoal be then heated to a certain degree, by means of a burning-glass or otherwise, the previous cohesion of its particles yields to their attraction for the oxygen of the air around them, and they immediately begin to combine with the oxygen so energetically as to produce a heat still much greater, accompanied by the light or incandescence of combustion. The charcoal, under these circumstances, soon entirely disappears, or is dissolved in the air, as sugar may be dissolved in water; but if the air be afterwards weighed, it is found to have gained in weight exactly the weight of the charcoal which has disappeared; and a chemist can again separate the charcoal from the air, and use either for any purpose as before. In like manner, if a piece of iron-wire be heated at one end, which is then plunged into a jar of oxygen gas, it will instantly light up and burn as a most brilliant taper, and will gradually fall in the form of oxidized drops, or scales of iron, to the bottom of the vessel. During this process the quantity of oxygen will be diminished, but if the scales mentioned be collected, they will be found to weigh just as much more than the original wire expended, as there is of oxygen lost or combined with them. A chemist can separate this iron and

oxygen, and exhibit them apart as before, without loss. Again, if iron and sulphur in certain proportions are heated together, they unite with vivid combustion, but the product will weigh exactly as much as the original ingredients.

966. While every instance of combustion is thus only a case of chemical union, going on with such intensity of action as to produce incandescence, still, according to the nature of the substances combining, the appearance will vary much. The union may take place, for instance, with flame or without flame. The great combining substance in nature, and which is also the most universally distributed substance, is oxygen, of which the name is now become familiar to the ears of even the unlearned. It forms nearly four-fifths of the substance of water, and one-fifth of our atmosphere, being on the latter account present wherever man can live, and ready to unite itself with any matter exposed to it at the necessary temperature. Now, of substances burning in air, those which are originally aëriform, as coal gas, or which, on being heated, are rendered aëriform before the union takes place, as oil or wax when much heated, assume the appearance of flame,—which means that the aëriform particles previously invisible are raised to the incandescent temperature; but when the mass of the substance combining with the oxygen remains solid, while its particles are gradually lifted away by the oxygen acting only at the surface, it appears, during the whole time, only as a red-hot stone. The latter is the case of charcoal, coke, Welsh stone-coal, &c.; while in the case of wood, common coal, &c., a greater or less portion of the inflammable matter is by the heat of the combustion converted into vapour, and so produces the beautiful appearance of flame.

967. Of the substances called combustible, and so called because they combine with oxygen so energetically as to become incandescent, there are only a few, as the metals called potassium, sodium, &c., which will begin to unite with oxygen, or to burn, at the common temperature of our atmosphere, the others requiring to be at some higher temperatures. Thus phosphorus begins to burn only at 150°, sulphur at 550°, charcoal at 750°, hydrogen at 800°, &c.; up to which temperatures the mutual attraction of the atoms of the substances among themselves is sufficient to resist the other attraction of the oxygen present. But when the combustion once begins, the temperature, from the effect of the combustion itself, rises instantly much beyond the degree necessary for the commencement of the process. Oxygen

and hydrogen, which begin to burn or combine only at 800°, instantly produce a flame of nearly as intense heat as human art can excite.

968. On the circumstance that combustible bodies require to have a certain preparatory warmth before beginning rapidly to combine with oxygen, depend many important facts in nature and art. Hence the safety with which ordinary combustibles may be exposed at ordinary temperatures to the contact of atmospheric air. Were it otherwise, any kind of coal or wood, &c., in the moment of being exposed to the air would catch fire, just as happens to phosphorated hydrogen gas, when allowed to rise into the atmosphere, or to the metal called potassium, which, when thrown into even cold water, attracts the oxygen of the water instantly, and burns intensely.

969. If a fire or flame be very small, the rapid absorption of heat from it by cold bodies around so lowers the temperature of the substance that the combustion is soon extinguished. Thus a common coal fire, if it be not watched, and the remaining fuel be not occasionally gathered together, to reduce the surface of wasteful radiation, will be extinguished long before the whole fuel is consumed; but not so with lighted wood or paper, which substances burn more readily than coal. The Welsh stone-coal can be made to burn steadily only when in considerable masses, or when mixed with a more inflammable coal or other fuel, or when surrounded by fire-brick, which retains the heat well, or when fed by air already heated. The manufacture of iron has lately been improved, and much cheapened, by causing the air which feeds the furnace to be warmed by passing through metal tubes heated in another fire. This proceeding constitutes what is called the *Hot-blast.*

970. A substance placed in unmixed oxygen gas burns with much greater intensity, and will begin burning at a much lower temperature than if placed in atmospheric air, which contains only about one-fifth of oxygen and four-fifths of nitrogen gas. The nitrogen does not aid the combustion, and by absorbing much of the heat of the combustion it lowers the temperature. Iron wire burns with intense light as a taper in oxygen, but will not burn in common air; and a common taper or flaming piece of wood extinguished by blowing on it will immediately be rekindled if plunged into oxygen. Again, a lamp with a very small wick, and, consequently, a small flame, producing very little heat, will not burn at all in cold weather, or in an ice-

house, and at any time will be extinguished by a cold foreign body brought near to it, a piece of ice, for instance, or a metallic nob held to it on the end of a wire, or a metallic ring let down over it; but if the ball or ring be hot, that effect will not follow. By more powerfully refrigerating processes, even a considerable lamp or candle may be put out.

971. These discoveries led Davy to the construction of his precious safety lamp for mines, which is merely a lamp enclosed in a lantern of wire gauze, of which the gauze meshes are of such a diminutive size that a flame of burning hydrogen gas attempting to pass through is so cooled by the heat-absorbing and heat-conducting power of the metal, as to be instantly extinguished. A piece of wire gauze gradually let down upon any common flame, thus annihilates the part of the flame which should appear above the gauze; but the combustible vapour then passing invisibly through the gauze may be lighted afresh on its upper side. Oxygen and hydrogen, which are the constituents of water, when uniting chemically, produce such intense heat that the momentary expansion of the newly-formed water, then in the state of steam, may cause a violent explosion. When a jet of oxygen and hydrogen already mixed gives a continuous flame, the most refractory substances melt in that like wax in a common taper,—yet these gases may be kept long mixed together in the cold reservoir of a blow-pipe without combining, and when set on fire at the jet of the blow-pipe, the flame does not travel inwards through the opening, as might be feared, because it is cooled by the metal of the orifice.

972. Solid bodies become very visible or incandescent at about the temperature of 1000° of Fahrenheit, but airs, owing to their tenuity of condition, require to be heated much farther before they exhibit the vivid appearance of flame; and airs of light atoms, like hydrogen, require to be heated still more than denser airs. Thus the flame of pure hydrogen is pale and blue, but a wire held in it becomes much more luminous than the flame itself; and the flame of mixed oxygen and hydrogen escaping from a very minute orifice in a glass tube, may itself be scarcely visible, while the extremity of the tube heated by it becomes like a brilliant star. Hence the light from some flames is much increased by placing a wire gauze or other solid body in the flame, as is seen when a piece of lime is placed in the flame of oxygen and hydrogen, to form what has been called the *Drummond Light.*

973. Consideration of this subject enables us to explain why common coal gas, which consists of hydrogen holding a quantity of carbon in solution, gives a stronger light than pure hydrogen, and why oil gas, which contains about twice as much carbon as the coal gas, gives also about twice as much light. The explanation is, that the oxygen of the atmospheric air, which first mixes with these gases as they issue to burn, is sufficient to combine with all their hydrogen, which it more strongly attracts, but not at the same time with all their carbon; the particles of the carbon, therefore, are at first separated, and being left for a time in the flame, become so many solid particles most intensely heated, and, therefore, very luminous; and afterwards, when they have ascended a little higher, they meet with new oxygen and burn or are dissolved in their turn, and disappear. That this decomposition of the gas really occurs is proved by placing a wire gauze across and near the middle of the flame. It becomes immediately loaded with particles of charcoal separated there, and cooled by it so as to cohere. If the gauze be close to the orifice where the carbon is not yet separated, it retains none, and if held beyond the top of the flame, where the particles are already burned, it retains none. A candle or lamp is said to smoke when the heat produced by it, or the quantity of oxygen allowed to approach the flame, is not sufficient to effect the total combustion of the carbon which rises in its flame. The hollow or circular wick of the common Argand lamp, and the similar form given to gas flames, is useful, by admitting air to the inside as well as to the outside of the inflamed jet, while the lofty glass chimney serves to quicken the current of atmospheric air which mingles there.

974. When atmospheric air, mixed with certain inflammable vapours, as ether, is allowed to be in contact with a moderately warm body, a very slow union may take place without producing flame. This phenomenon has been called invisible combustion. It is remarkably exemplified on placing a small coil of platinum or gold wire, moderately heated, in such a mixture: the combination of gases then goes on in the immediate vicinity of the hot wire, and although without flame, still with sufficient disengagement of heat to maintain the wire in a feebly luminous state, as long as there are gases left to combine. Thus the vapour always arising at a common temperature from the open mouth of a phial containing ether, if made to pass through a coil of platinum wire, will, while combining by this

slow combustion, with oxygen from the air around it, give out heat enough to keep the wire so luminous as to serve in lieu of a little lamp by which to read from the dial plate of a watch through the night.

"*Fuel.*"

975. HEAT being, in the sense already explained, the life of the universe, and man having command over nature chiefly by his power of controlling heat, which power again comes to him with the ability to produce combustion, it interests him much to inquire what substances he can most easily procure as supporters of combustion, or *fuel.* The all-important substance, oxygen, forms part of our atmosphere, and therefore penetrates, and is present wherever man can breathe, ready at once for his service. Then for the purpose of combining with the oxygen there are chiefly two other substances also very abundant in nature—namely, carbon and hydrogen, which are the great materials of all things of vegetable origin, as trees, bushes, grasses, &c., and therefore of coal-beds, many of which are evidently the condensed remains of forests which existed in remote past time. Carbon is found nearly alone in the hard coal called anthracite, or stone-coal, but it is united with a large proportion of hydrogen in caking or bituminous coal, and in wood, resins, tallow, and oils. The inflammable gas obtained from these last-mentioned substances, and now used for illumination, is merely hydrogen, holding in solution certain proportions of carbon. All bodies which burn with flame give out gas while in the act of combustion. The stones, earths, water, &c., seen at the surface of this globe, are already saturated combinations of other substances with oxygen, and are, therefore, not in a state to produce further combustion. Carbon and hydrogen, by various processes of vegetable and animal life, are always in numberless situations being combined and accumulated, so as to become fit for fuel.

976. The name fuel has been given to the substances which combine with oxygen, and not to the oxygen itself, because the former, being obvious to the senses as solids and liquids, had attracted notice as producers of combustion long before the existence of the aëriform agent, oxygen, was even suspected.

Oils, fat, wax, &c., from becoming gaseous in their combustion, exhibit the appearance of flame, as already explained, and hence are used chiefly for the purpose of giving light; while wood and coal are more frequently used for mere heating. But the chemist's oil-lamp and gas-furnace, by which he distils, evaporates, and melts, and the gas apparatus of a kitchen, prove that it is chiefly the greater expense of gaseous fuel which has limited it so much to the office of light giving.

977. Wood was the common fuel of the early world when coal-mines were not yet known, and still in many countries it is so abundant as to be the cheapest fuel. Charcoal is the name given to what remains of wood after it has been heated in a close place, during which operation the hydrogen and other minor ingredients are driven away in the form of vapour. Charcoal is nearly pure carbon. Coke, again, is the charcoal obtained by a similar process from coal. Wood, common coal, and oil, if much heated in the open air, burn or combine with the oxygen of the air; but if heated however much in a vessel or a place which excludes air, they do not burn but merely give out their more volatile parts in the form of transparent inflammable gas to be burned elsewhere.

978. Good coal, where it abounds, is now for ordinary purposes by much the cheapest kind of fuel; and since within a short time men have learned to separate from it, and to use instead of tallow, oil, and wax, in suitable lamps and candles, its illuminating gas—namely, its hydrogen holding in solution carbon, it has become doubly precious to them. A person reflecting that heat is the magic power which vivifies nature, and that coal is what best gives heat for the endless purposes of human society, cannot without admiration think of the rich stores of coal which exist treasured up in the bowels of the earth for man's use. And Britain in this respect, is singularly favoured. Her extensive coal-mines are in effect mines of latent labour or power vastly more precious than the mines of gold and silver elsewhere. These coal-mines may be said to afford in abundance, although not directly, every thing which human labour and ingenuity can produce, or which money can buy; and they have essentially contributed to render Britain a leader in the industry and commerce of the earth. Britain has become for the time to the civilized world around, nearly what a town is to the rural district in which it stands, and of this vast and glorious city the mines in question are the coal-cellars, stored at a moderate rate of consumption for more than 1,000 years; a supply which, as coming improvements in the arts of life will naturally bring economy of fuel, or substitution of other

means to effect similar purposes, may be regarded as being a very valuable provision.

979. The coal in many mines is evidently the remains of vegetable growths which existed in very remote time. In many coal-beds the trees yet retain their form, so that their species can be easily distinguished, and there are buried among them other vegetable and animal remains of the same ages. Coal is found of different qualities. In some places it is almost unmixed carbon, and exceedingly solid, like dense coke, resulting from great pressure and great subterranean heat. Such is the stone-coal of Wales, some of which in 100 parts contains 97 of pure carbon, with only three of hydrogen and earthy matter. In other places the coal contains hydrogen in nearly as large proportion as wood does, and in some places the hydrogen and carbon are so combined as to be in the soft condition of pitch, tar, or oil.

980. The comparative values, as fuel, of different kinds of carbonaceous matter, have been found to be as in the following tables:—

One Pound of	Melts of ice.
Good coal	90 lbs.
Coke	84 ,,
Charcoal of wood	95 ,,
Wood	32 ,,
Peat	19 ,,

Lavoisier, in making experiments on combustibles generally, to ascertain the quantities of oxygen consumed, and of heat given out during the combustion of a given quantity of each, obtained the following results:—

One Pound of	Melts of ice.	Takes of oxygen.
Hydrogen gas	370 lbs.	7 lbs.
Carburetted hydrogen	85 ,,	4 ,,
Olive oil	120 ,,	3 ,,
Wax	110 ,,	3 ,,
Tallow	105 ,,	3 ,,
Charcoal	95 ,,	$2\frac{2}{3}$,,
Phosphorus	100 ,,	$1\frac{1}{3}$,,
Sulphur	25 ,,	1 ,,

981. Common coal consists, as explained above, of carbon and bitumen or pitch, of which pitch again, the chief element, is still carbon combined with hydrogen, one of the substances which, when separate, exist as air or gas. This pitch evaporates at a heat of about 600° of Fahrenheit, while that of combustion exceeds

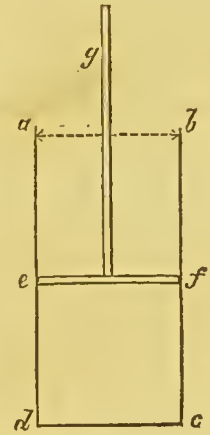
1000°. When fresh coal, therefore, is thrown upon the top of a common fire part of it is soon heated to 600°, and the bitumen of that part begins to rise as visible opaque smoke. It is this which in great towns darkens the atmosphere, blackens the exterior of all the buildings, and produces many other evils. By managing a coal fire, therefore, so that it shall burn or destroy its smoke, as may be done in various ways, not only is a great nuisance prevented, but a great saving is realized. The loss arises because the heat, which the combustion of the hydrogen and carbon of the smoke would produce, is not obtained, and because these substances, in assuming the gaseous form, absorb much heat into the latent state. Details on this subject are given in a treatise published by the author in 1855, "On the Smokeless Fire, Warming, and Ventilating," to which the reader is referred. There is no good reason why the atmosphere of London should not be rendered as clear as that of the great city of New York in America, where only stone coal is burned, or of St. Petersburg, Berlin, and the other European cities, where winter heating is obtained altogether through close stoves.

"*In the heat artificially produced through combustion, man commands the power or force required to render active for their purposes all the forms of machinery which he has invented.*" (Read the Analysis, page 406.)

982. It is within the last twenty-five years that scientific men, as Dr. Joule and others in Britain, Dr. Meyer, and others in Germany, have devised means of measuring accurately the expansive force of heat as a mechanical agent, and have detected many important relations existing between heat and the other forms of force operating throughout nature.

983. We may recall that to measure anything is to adopt some convenient amount or quantity of that as a unit of reference, and then to find how often that unit is contained in any new quantity. Thus, if a convenient handful of some substance be called a pound-weight, any other quantity of ponderable matter is accurately measured when the number of such pounds contained in it is ascertained. So if the average length of a human foot be called a foot-measure, any greater length is determined by finding the number of such feet contained in it. It follows that a foot square is a convenient

unit for surfaces, and a foot cube for bulks. A measure for temperature is the length of the mercurial column of a thermometer standing between the fixed points of freezing and boiling water, when divided into a certain number of equal parts, to be called unit degrees of temperature. Then for quantity of heat, as distinguished from temperature, a convenient unit is that quantity which just suffices to raise the temperature of one pound of water one degree of the standard thermometer. Lastly, in relation to the present subject, a convenient *unit of force* is that which can lift one-pound weight through one foot of height,—an amount now called a *foot-pound.* By referring to such standard units once chosen and generally agreed upon, all questions respecting the mechanical equivalents of heat and other forms of force can be satisfactorily answered. An example follows.



984. Let the outline *a, b, c, d,* indicate a vessel like the barrel of a pump or steam-engine, of a foot square in transverse area, having in it a moveable close-fitting piston *g, e, f.* That piston, when one foot from the bottom, would shut up below it in the space *e, f, c, d,* just one cubic foot of air. The surface of the piston being an area of a square foot, or 144 square inches, will be bearing on its upper surface the atmospheric pressure of 15 pounds on every inch, in all 2160 pounds or twenty hundred-weight, which in a state of rest will be exactly balanced by the resisting elasticity of the confined air below the piston (See Article 555). Now experiment ascertains that by giving heat to produce 490 additional degrees of temperature in the air beneath the piston, the bulk or volume of that air will be just doubled, and it will gradually push up the piston to the line *a b,* two feet from the bottom. Thus rising, the piston lifts a weight of 2160 pounds through one foot of height. If, instead of the atmosphere pressing down the piston, there were a mass of 2160 pounds of lead resting on it and no air, the result would be the same.

985. Then, knowing further the weight of a cubic foot of air, and the so-called capacity for heat of air at different densities, as compared with equal weight of water, the computation is easy, as explained in the Appendix, of the small quantity of heat absorbed or expended in lifting the vast weight. The

ascertained fact is, that the amount of heat which warms one pound of water one degree of Fahrenheit (the so-called thermal unit) has force to lift one pound weight of anything 772 feet, or a weight of 772 pounds one foot. This expansive force of the unit of heat, as compared with the downward force of gravitation, is called the mechanical equivalent of 772 foot-pounds.

986. Persons before studying this subject, would be far from thinking that so small an amount of heat could produce such powerful mechanical effect, but now there is no room for doubt. This fact, when once understood, explains many other marvels; for instance, the force of a single steam-engine doing the water-pumping work of six hundred strong horses. Then it is the force of the sun's hot rays which is daily lifting to the clouds, in evaporation from the water surfaces below, the enormous quantity of water which falls again all over the globe as rain and snow, ultimately to fill the countless river-channels, great and small, which return it to the sea. Then it is the heat of the sun which produces all the motions of the atmosphere called winds, including the variable breezes of temperate climates, the strong and steady trade-winds of the tropics all round the earth, and the furious hurricanes which occasionally sweep over wide regions. And, lastly, the whole surface of the ocean is constantly heaving in waves, low or lofty, produced by force of the wind blowing upon it.

987. In the last paragraphs are set forth phenomena in which heat acts mechanically to produce motion in heavy masses, with force exactly proportioned to its quantity. We have now to state, as new knowledge, that motions of masses so produced can, when suddenly arrested by obstacles, reproduce the exact amount of heat which caused them, either of the two forms of force being thus convertible into the other.

It had long been familiarly known that certain motions of masses, while exhibiting the phenomena of friction, percussion, condensation, and others, generated heat, but the relations were not accurately determined. Thus a soft iron nail laid upon an anvil, and receiving in rapid succession powerful blows of a hammer, becomes hot enough to light a match. In the case of the mutual percussion of flint and steel in the old gun-lock, small portions of one or both are struck off in a state of white heat, and the particles of the iron burn in passing through the air. The heat produced by rubbing strongly against each other two pieces of dry wood is the means commonly used among savages to light their fires. Men warm their cold hands in winter by rubbing them against each other, or against their coat-sleeves. The axletree of a heavily-laden waggon, if left without oil, may be heated so as to inflame the wood. The line attached to a whale harpoon, as it runs over the side of the boat, when the whale dives after being struck, requires to have water constantly thrown upon it to prevent it setting fire to the boat. The cable of a ship drawn very rapidly through the hawse-opening produces there intense heat and smoke. When a great ship is launched from the builder's yard, and glides along the sloping beams to the water, a dense smoke usually rises from the points of rubbing contact.

988. In these cases, however, the amount of heat produced seemed variable, and had not been accurately measured until the experiments made lately by Joule, Meyer, and others, which have proved that the quantity of heat is exactly proportioned to the mechanical force expended. Thus, a body falling from a height, and arrested by collision with another body on the ground, produces just as much heat shared between the two as, if again used to dilate air or steam, would lift the body to the height from which it fell; nearly as the momentum of a pendulum acquired by descending from one side of its arc to the centre, just suffices to lift it to the same height on the other side. Any liquid poured out and falling into a vessel below, becomes hot in exact proportion to the height of fall. Any liquid, as water, oil, mercury, &c., driven round or churned in a vessel by a paddle-wheel moved by a falling weight, is warmed just in proportion to the weight and the height of its descent. Count Rumford, by the friction of a boring instrument in the barrel of a cannon, driven by horse-power, heated water around the cannon in exact proportion to the time during which the horse had worked.

989. It has now been discovered that there are similar relations and correspondence between heat and other forces and actions, as of electricity, chemical combination, or decomposition, muscular power, &c., and it appears that all these are convertible into one another in fixed proportions. The word energy has been employed as a general term for all, and when any one disappears, the assumption is that the form only is changed, while the energy remains, as, for instance, when the sensible motion and

momentum of a falling body are changed into the heat which follows the impact on the ground; and the heat is said to be motion in the minute particles of the body among themselves. Much has yet to be learned respecting these phenomena.

> "*Man by the command which he has acquired over heat and fire, can produce artificially the climate which suits his constitution in any part of the globe.*" (Read the Analysis, page 406.)

990. It is a remarkable fact in nature that living animal bodies have the property of maintaining in themselves a certain nearly uniform temperature, whether surrounded by bodies that are hotter or colder than themselves. Persons passing the winter near the north pole, where they are breathing air cold enough to freeze mercury, still have in them their natural warmth of 98° Fahrenheit; and the inhabitants of India, where the thermometer sometimes stands at 115° in the shade, have their blood only 98° warm.

991. The chief source of animal warmth is a kind of slow combustion which takes place in the lungs between the oxygen of the air which enters the chest in breathing, and carbon derived from the food which is passing through the vessels of the lungs in the circulating blood. The carbonic acid gas which is then formed is expelled, and being hurtful to life if breathed again, like that formed in a charcoal fire, is carried away by ventilation. Again, the warmth is controlled or prevented from being excessive by copious perspiration or evaporation of moisture from the skin and lungs. Dogs, when much heated by exercise or by the weather, as they cannot throw off or diminish their natural covering, increase the evaporating surface by protruding a long humid tongue.

992. The power in animals of preserving their peculiar temperature has its limits. Intense cold coming suddenly upon a man who has not sufficient protection, first causes a sensation of pain, and then brings on an almost irresistible sleepiness, which if indulged proves fatal. Sir Joseph Banks, in one of his voyages, having gone on shore near the cold Cape Horn, and being fatigued, was so overcome by the feeling mentioned, that he entreated his companions to let him sleep, if but for a few minutes. His request, if granted, might have allowed to come upon him the sleep of death, as befell so many of the hostile

army retreating from Russia through the snows of 1812, when in one night the thermometer fell to 19° below zero, and according to the bulletin 30,000 horses perished besides men. Cold in less severe degrees, acting through longer periods on persons imperfectly protected, induces a variety of diseases, which destroy more slowly; as many of the winter diseases of England.

Every kind of animal has a temperature proper to it, and in the diversity are found creatures fitted to live in all parts of the earth, what is wanting in internal bodily constitution being found in the admirably adapted covering which protects them—covering which grows from their bodies, with form of fur or feather, in the exact degree required, and even so as in the same animal to vary with climate and season. No such covering is possessed by man; but his reason, by which he subjects all nature to his use, enables him to clothe himself as befits the part of the globe in which he chooses to dwell.

993. The human race when not possessing certain arts of civilization, naturally inhabit a warm climate, such as exists over vast regions on both sides of the equator. There the sun's influence is strong and uniform, producing a rich and warm garden, in which human beings, however ignorant of the world around them, would have all their necessities at once supplied. The ripe fruit is there always hanging from the branches; of clothing there is required only what moral feelings may dictate, or what may be supposed to add grace to the form; and as shelter from the weather, a few broad leaves spread on connected reeds, complete the tropical hut. The human family, in multiplying and spreading in all directions from such a centre, would find, to the east and west, only the lengthened paradise, with slightly varying features of beauty; but to the north and south the changes of season, which cause the bee of high latitudes to lay up its winter store of honey, and send migrating birds from country to country to find the required warmth and food, would also rouse man's energies to protect himself. His faculties of foresight and contrivance would come into play, awakening industry; and through these he would in time possess the knowledge and the arts which secure to him a happy existence in all climates, from the equator almost to the pole. And it is chiefly because man has learned to produce at will, and to control, the wonder-working principle of heat, that in the rude winter, which seems the death of nature, he, and

other tropical animals and plants which he chooses to protect, do not in reality perish—as does a tame canary bird escaping from its cage, or a traveller losing his way among drifting snows. By producing heat from his fire, man obtains a novel and most pleasurable existence; and in the night, while the freezing winds are howling over his roof, he basks in the presence of his mimic sun, surrounded by happy friends and all the delights of society; while in his store-rooms, or in those of others at his command, may be treasured the desired things of every season and clime. He then becomes aware, that the winter, instead of being an unmixed evil, is really in many respects a blessing, by arousing from the apathy to which the unvarying serenity of a tropical sky so much disposes. He sees that in climates where labour and ingenuity must precede enjoyment, every faculty of mind and body is invigorated; and that hence the sterner temperate climates produce the perfect man. In these chiefly have the arts and sciences reached their highest advancement, and the brightest examples have arisen of intellectual and moral excellence.*

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* Artificial Climate *producible by the arts of warming and ventilating.*

The writer has treated this subject at considerable length in his work published by Longman and Co., referred to in Art. 981. He gives a brief outline in this note.

The four essentials to the life and health of human beings are,—fit *air*, *warmth*, *aliment*, and rest, alternating with action. An individual if deprived of the first, dies in a few minutes, as by drowning or other suffocation; if deprived of the second, he dies in a few hours, as when overwhelmed in a snow-storm; if deprived of the third, he dies in a few days, as when left on a bare rock after shipwreck; and if deprived of the fourth, he dies in a few days, weeks, or months, according to other circumstances. Want or faulty management in regard to the first two of these are the chief causes of much of the imperfect health and the premature mortality suffered by the inhabitants of changeable climates.

It is not yet a century since, through the labours of scientific men, and chiefly of Priestley, Lavoisier, Rumford, and Davy, it was discovered that atmospheric air consists of two ponderable substances, of which oxygen is one; and that the phenomenon of combustion or fire arises during the very energetic chemical combination of oxygen with other substances called fuel or combustibles.

Human beings living in the savage state without houses use fire principally for the purpose of cooking food, the fuel being wood burning on the ground in the open air. A very small portion of the heat so produced is turned to account, the gross amount being dissipated into space, partly by radiation and partly by being carried away in combination with the smoke.

Of fire burning in an enclosed space all the heat is retained, giving warmth to the substance of the walls and to the air within them. It would have been, therefore, a very simple affair in cold weather to warm a closed apartment to any desired degree by lighting a fire in it, but for the fact that the smoke and other products of combustion, if breathed in a concentrated state by animals, are destructive to life.

When the object was, therefore, to warm the air in any dwelling by a fire, it was found necessary to have an opening in the roof or ceiling by which the smoke might escape; or the fire had to be made in an enclosed space beneath the floor, through which the heat would slowly penetrate by conduction; or it might burn in a close receptacle in the room, to be called a stove, constructed of brick or other material, and having a channel for smoke leading directly to the outer atmosphere. In England, up to a late time, it was common in spacious halls, as of colleges, courts of law, and elsewhere, to have a great brazier or hearth near the middle of the room, with an opening for smoke in the ceiling above.

It was an important advance in the art of warming rooms by open fires, when the fuel was placed against the wall to radiate around, and a chimney-flue was constructed in the wall over it to carry away the smoke without allowing any mixture with the air of the room. The arrangement of the fireplace and chimney in the wall had become general in this kingdom in the last century.

In countries where the winters are colder than in England, as the northern continental parts of Europe, it is found that sitting-rooms cannot be satisfactorily warmed by open fires of any magnitude, because of the loss of heat through the wide chimney, and in consequence close stoves of masonry or of metal are universally used, as well in royal palaces as in the dwellings of the poor, and not from the motive of saving fuel, but for the sake of comfort and health.

At the beginning of this century, Benjamin Thompson, more commonly known as Count Rumford, while engaged with other philanthropists in establishing the Royal Institution of London, in which, since then, Davy, Faraday, and other distinguished men have laboured so usefully for the public good, proved that in the common open English fireplace more than seven-eighths of the heat produced mounted with the smoke to waste; and he ascertained and taught that the single change of narrowing considerably the throat of the chimney would save nearly half the fuel. Innumerable projects for further improvement have since then been offered, for which patents have been taken, mostly, however, by persons who had little scientific knowledge on the subject, but none of them have been accepted, like Rumford's, as generally useful. The present writer having, in his professional experience, seen how many of the diseases occurring in winter are caused by errors committed in regard to warmth and ventilation, was led in 1838 and 1855 to publish a short treatise on the subject for popular instruction, and to suggest remedies for certain of the evils. The Council of the Royal Society honoured him in 1856 by the award of the Rumford Medal, in testimony of their approval of what he had done.

The following description of the wasteful open fireplace and its action will bring the subject before the reader.

The grate is a cage or receptacle for fuel, about ten inches deep, fourteen inches broad, and nine or ten inches from back to front. It has usually three bars of iron in front, the sides and back are of iron or fire-brick, and the bottom is an iron grating allowing air to enter and ashes to fall out. There is left a large open space between the fire and the smoke-flue above causing much of the waste. To prepare for lighting, the grate is charged with common bituminous coal, having firewood and paper beneath. When the paper is lighted, combustion gradually spreads, causing much smoke to arise, part of which is deposited in the flue as soot. Slight causes may send part of the smoke back into the room. The fuel being consumed rapidly, has to be frequently renewed, and hence there are required constant attention and poking to obtain any approach to uniform action. Strong currents of chilling air flow from the door and windows towards the chimney.

A great aim in regard to such open fire has been to lessen the formation of smoke. Dr. Franklin, of America, proposed to place the burning fuel in a moveable cage, and after fresh fuel was introduced at the top, to turn the cage half round, so that the smoke of the new fuel should pass through the ignited fuel above, and be there burned; but unforeseen difficulties presented themselves. Other inventors made complex mechanical apparatus to force up coal from below through the bottom of the grate, but their plans also, from the expense and frequent failure, were abandoned. The present writer saw that much good might be obtained by causing the fire to burn from above downwards as a candle does, and by using the poker as a simple lever to lift the fuel on a moveable bottom. This arrangement is now employed to a considerable extent.

Many common English grates, by slight inexpensive changes, can be made to effect several of the ends sought, thus—

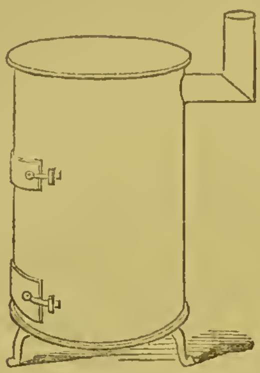
1st. The surfaces of the back and sides of the grate may be continued vertically, in fire-brick or otherwise, to the chimney-throat, so as to narrow much the open space between the burning fuel and the throat. This prevents the great waste of heat caused in common grates by the mixing of much of the pure warmed air of the room with the smoke, which has to ascend the chimney to depart. 2nd. A throttle-valve, or a sliding damper may be placed in the chimney-throat, with its handle projecting in front, so that the size of the passage may be regulated at will, and its state may always be known. This damper can be always so far closed as to leave passage for little more than the true smoke, or hot foul air rising directly from the fire. Thus will the flue be filled with hot air, almost undiluted, and the great heat will cause chimney-draught much stronger than exists with the common grate, absolutely preventing any return of smoke into the room, and which, when desired, can urge the fire almost like a bellows. Such chimney-draught will also quicken remarkably the ventilation of the room through the opening made near the ceiling to receive the balanced ventilating-valve, now in very common use, and it may be made to draw through that opening the hot impure air arising from the burning of candles or lamps, or from other sources. 3rd. On the bottom of the grate can be laid a plate of sheet iron, covering it to within about half an inch of the border all round, so that only a little air shall enter there, and a length of plate iron may be placed to rest on edge, as a lining or shutter between the lower bar and the bottom of the grate—still further preventing the entrance of air there. 4th. To prepare for lighting the fire at the top and making it burn downwards, the grate may be filled with common coal to near the level of the upper bar, and upon that pieces of twisted paper and firewood will be laid as usual, and over the wood a layer of the cinder or caked coal left from the fire of the preceding day. The combustibles being so arranged, and a match being applied to the paper, the fire, by reason of the strong draught, blazes up with singular rapidity. It will burn for many hours, and if the grate be deep, even for the whole day, without being touched. In the evening, when the fuel is nearly consumed, the fire may be extinguished instantly by lifting off one or two of the remaining pieces. At any time when desired, the fire, by a touch of the poker, and sometimes by the application in front of a sheet blower, may be excited to great activity. The writer, years ago, had the old fireplace of his library altered in the way now described, and the result has been quite satisfactory. Fresh air is admitted to the room through a channel from the outside, which discharges under the fender, and that air, tempered by contact with the warmed fender, is then diffused all around.

A grate, constructed to act without re-charging for a long day, as above described, has beneath the firebox a receptacle for coal, which coal, supported on a moveable piston-like bottom, can be easily raised when there is need, by a hand using the poker as a simple lever. At any time a lump of coal placed on the very hot upper surface of this fire blazes quickly and lasts long, giving out hardly any smoke.

Since the publication of the writer's book, various manufacturers have engaged in making stoves with the simple lever to lift the coal, but wishing to claim some peculiar new merit, have deviated so as to fail. The grates which for years have given satisfaction in the writer's drawing-rooms, were placed there by Messrs. Bailey, of 272, Holborn.

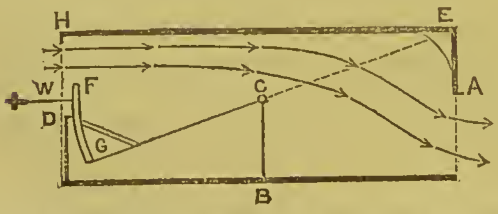
As when this fireplace is properly arranged it cannot disappoint, there is hope that intelligent makers will undertake to provide them on the condition of taking back a grate which does not answer. An incompetent maker would scarcely engage in the business if bound by that condition.

The Close Stove.—The old form of this, with its narrow flue to carry away the smoke, is here sketched. By such a stove, a close room can be readily warmed to any desired temperature at the cost of a fourth part of the fuel required in an open grate. But the common stove has important defects. It scarcely at all promotes the ventilation of the room, although in any place without change of air, persons would soon be suffocated. It may vitiate the air of the room by becoming overheated; and there is much difficulty in regulating satisfactorily the rate of combustion. Notwithstanding the objections, close stoves are the chief means of warming dwelling-houses during the winter in the northern parts of continental Europe. The present writer, when his attention was drawn to the subject, in relation to the preservation of health, saw the possibility of connecting with the stove such a self-acting current-regulating air-valve as can remedy completely the evils above referred to.



He has had in his dining-room a stove so regulated for more than twenty years. The fire in it is lighted in October, and burns uninterruptedly night and day until May of the following year. The servants have to touch it only when putting in coal at bedtime, and raking out the little ash in the morning, with trouble scarcely greater than that of winding up a clock. It maintains in the room a temperature of about 62 degrees of Fahrenheit, or higher if desired, and the room-door being left open, except at meal times, the warmed air issues to the staircase, and so pervades the whole house. An air channel under the floor, direct from the outer atmosphere, having an area of eight inches by four, admits fresh air immediately under the stove to be warmed, and to spread. The family, in consequence, have been free from winter illnesses when these were common in the neighbourhood. Experience in many other cases has shown that such a self-regulating fire in the entrance-hall of a house, goes far to secure to the inhabitants the advantages of the climate of the south of Europe or Madeira, and could save to many invalids the pain of banishment from home and its comforts.

The current-regulating air-valve for close stoves, on which their important qualities depend, occurred to the writer while composing his "Elements of Physics." A perfect simple current-regulator was until then a desideratum in art for various important purposes. Many forms were devised, of which one, because the most easily explained by a sectional diagram, is here sketched.

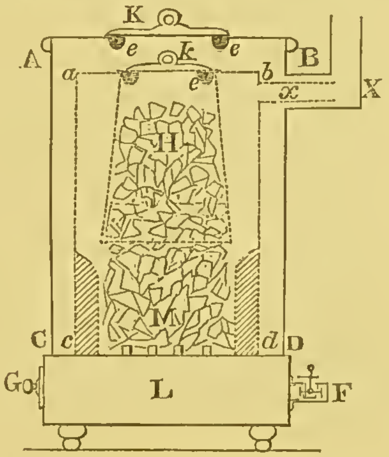


The strong lines mark the external square tube or case, about four inches long, and half as wide, to be fitted on by the end A to an entrance of the ashpit.—The arrows show the direction of the air current passing through. The line E G marks the moveable internal part which modifies the current. It is a lever frame perfectly balanced and turning on the upper edge of the cross partition C B as its axis. One half or arm C E of the lever is a breadth of wire gauze through which the current of air forces itself, causing a downward pressure and motion. The other arm C G F carries at its end a bent plate G F (here seen edgeways), which, on being raised as the lever moves, becomes a shutter narrowing the air-entrance H D.

The self-weakening action of the current would soon extinguish a fire dependent on it, if there were not a small weight W placed near the extremity of the arm at F, which counteracts, and by pressing down the shutter F G, admits just air enough for its purpose, and the current then continues quite uniform until changed by lessening or increasing the weight W, or altering its power by moving it nearer to or further from the centre of motion C. It will be observed that the current blowing perpendicularly on the bent plate E G has no effect either to raise or lower it.

This kind of valve may be put on any close stove with much advantage, and is an important addition to all channels serving for ventilation. Among the makers are Messrs. Bailey, 272, Holborn, and Mr. Griffin, 120, Bunhill Row. Further details, reporting recent experience, will be given in an Appendix to the work on warming and ventilating.

The adjoining woodcut exhibits in section the complete self-regulating self-feeding close stove above referred to.



The letters A B C D mark the external case, which prevents the intense heat of the inner stove *a b c d* from damaging the air of the room. It is not allowed to be hotter than a tea-urn containing boiling-water.

F is the regulating valve, *c* and *d* the fire-brick lining of the fuel-box.

H the coal reservoir or hopper containing coal enough to last for twenty-four hours, which falls down as the coal below is consumed. It is charged with coal through the lids *k* and K, both of which are rendered air-tight by having their turned-down rims or edges dipping into grooves filled with sand, at *e e*.

The burned air from the fire M rises up in the space between the hopper and the inner stove case, to pass away by the internal flue *x* into the other flue X of the outer case.

L is the ash-pit, G the ash-pit door,—ground close.

M is the fuel intensely ignited below, where the fresh air is entering to maintain combustion.

The fuel must be good stone-coal or coke, and not common bituminous coal producing gas, which might suddenly inflame.

In concluding this chapter on HEAT, it seems befitting to advert again to the two important facts: 1st. That much of the disease causing premature mortality among men is produced by ill-managed temperature, dependent often on faults of ventilation; and 2nd. That the store of coal-fuel in the bowels of the earth applicable to human purposes is limited, and may be exhausted.

Coal in combustion is now the great agent which in the recently-invented steam-engine is performing nearly all the heavy work of the advanced civilization of the present day. It is doing the work of our railways and steam-ships, of the great manufactories which spin and weave our clothing, of the mines from which the coal itself is extracted, and the crude ore which coal in furnaces then converts into precious iron; and it gives us the gas for lighting, which now almost changes night into day. But unlike corn and fruit, and the herds of tame animals, on which men subsist, all of which are as regularly renewed year after year as they are consumed, the coal of a mine when once exhausted is never replaced. The high station of England at present among the nations is due in no small degree to the extraordinary wealth of coal found beneath its surface. Yet when the British Association for the Advancement of Science held its meeting at Newcastle in 1863, the president, Sir W. Armstrong, had to show, in his opening address, how rapidly the store of coal in this country is being reduced. The annual consumption, including exportation abroad, is now nearly seventeen times greater than it was at the beginning of the century. He stated his belief, which is that also of the present writer, that with better management in the domestic use of coal, very superior results may be obtained with largely diminished consumption. To waste this precious fuel is not to act like prudent parents thinking of the interest of descendants.

PART IV.

SECTION II.—ON LIGHT AND OPTICS.

ANALYSIS OF THE SECTION.

Light is an emanation from the sun and other self-luminous bodies, becoming less intense as it spreads, and which, by falling on other bodies, and being reflected from them to the eye, renders them visible. Its absence is called darkness. It moves with great velocity, and in straight lines where there is no obstacle,—leaving shadows where it cannot fall. It passes readily through some bodies—which are therefore called transparent,—but when it enters or leaves their surfaces obliquely, it suffers at them a degree of bending or refraction proportioned to the obliquity. A beam of white light thus refracted does not all bend equally, but is divided or resolved into beams of the different colours seen in the rainbow, which colours, on being again blended, become the white light as before.

Transparent substance, as glass, may be so formed as, by the power of refraction due to form, to cause all the rays which pass through it from any point on one side of it to bend and meet again in a corresponding point beyond it called a focus, and after so meeting and crossing, to pass on as before;—the body then, because in form somewhat resembling a flat bean or lentil, being called a LENS. *When the light thus proceeding from every point of an object placed before a lens is collected at corresponding points behind it, a distinct image of the object is there produced, visible from any situation on a white screen placed to receive it, or in the air, if viewed from behind. The most important optical instruments and even the living eye, are merely different arrangements of parts for producing and examining such images as now described. When the image is received upon a suitable white surface or screen in a dark room, the arrangement is called, according to minor circumstances, a* CAMERA OBSCURA *(that is, a dark chamber), a* MAGIC LANTERN, *or a* SOLAR MICROSCOPE. *And even the living* EYE *is, in fact, but a small camera obscura, enabling the mind to judge of external objects, by the size, brightness, colour, &c., of the very minute but most perfect images or pictures formed at its back part, on the smooth screen of nerve called the retina. The art of painting aims at producing on a larger scale such a picture as is formed on the retina, which when afterwards held before the eye, and reproducing itself in miniature upon the retina, may* *excite nearly the same impression as the original objects. When the image beyond a lens, formed as above described, is viewed in the air, by looking at it from behind, in the line of the axis of the lens, there then exists the arrangement of parts constituting a* TELESCOPE *or a* MICROSCOPE. *Rays of light falling on very smooth or polished plane surfaces, are reflected so exactly in the order in which they fall, as to appear to the eye receiving them to be coming directly from the objects originally emitting them—and such surfaces are called plane mirrors. Mirrors may be plane, convex, or concave; and certain concave forms concentrate light, to produce images by reflection, just as lenses produce them by refraction; so that there are reflecting telescopes, microscopes, &c., as there are refracting instruments of the same names. Light, again, falling on bodies of rough or irregular surface, or which have other peculiarities, is so modified as to produce all the phenomena of colour and varied brightness seen among natural bodies, and giving to them their distinctive characters and beauty.*

"*Light.*"

994. The phenomena of *light* and *vision* have for all minds surpassing interest, whether in regard to the beauty of light, or its utility. The beauty is seen spread over a varied landscape —in the verdure of fields and forests, among the beds of the flower-garden, in the plumage of birds, in the clouds around the rising and setting sun, in the circles of the rainbow. And the utility is such that if man had needed to supply his wants by groping in utter and unchangeable darkness, even if originally possessed of all the knowledge now existing in the world, he could scarcely have secured his existence for one day. Eternal night would have been universal death. Light, then, while the beauteous garb of nature, is also the absolutely necessary medium of communication between living creatures and the universe around them. The rising sun is what converts the wilderness of darkness which night covered, and which, to the mind of a child not yet aware of the regularity of nature's changes, is so full of horror, into a visible and lovely paradise. No wonder, then, if in early ages of ignorance, man has often been seen bending the knee before the glorious sun to worship in it the God of Nature.

995. A man, wherever placed in light, receives by the eye from every object around, nay, from every point in every object,

and at every moment of time, a messenger of light to tell him what is there, and in what condition. Had he the power of flitting from place to place with the speed of thought, he could not be more promptly informed. Then, in many cases where objects of interest are near, light can impart at once knowledge respecting them, which, by any other conceivable means, could come but tediously, if at all. For example, when the illumined countenance of a companion is revealing the secret workings of the mind, the tongue would in vain try to speak, even in long phrases, what one smile of intelligence or affection can in an instant convey. Then had there not been light, man never could have suspected the existence of the miniature worlds of life and activity, which, even in a drop of water, the microscope discovers to him; nor could he have formed any idea of the admirable structure of the very minute objects of nature. It is light again which, pouring upon the eye through the telescopic tube, brings to this earth intelligence of other worlds and other suns existing in the remote regions of space.

"*Emanation from the sun,*" *&c.* (Read again Analysis, page 497.)

996. In tropical countries, where the sun rises and sets almost perpendicularly, not allowing the long dawn and twilight of temperate latitudes, the change from perfect darkness to the overpowering effulgence of day, and the contrary change in the evening, are so sudden as to be highly impressive. An eye turned in the morning to the east has scarcely noted a commencing brightness there, when that brightness has already become a glow; and in a few minutes the sun has risen, displaying his breadth and glory, soon too bright for the eye to dwell upon. With evening the same appearances recur in a reversed order, ending, as in the morning they began, by complete darkness.

Light emanates also from the stars, but they are so distant as in that respect to be of little importance to this earth. And all bodies in combustion, or when heated to the temperature of ignition, are self-luminous.

997. There have been two opinions respecting the nature of light; one, that it consists of extremely minute particles darting all around from the luminous body; the other, that the phenomenon is altogether dependent on an undulation in the

substance of a very subtile elastic fluid diffused through space—as sound is dependent on an undulation among air-particles. The latter opinion is now that generally accepted, although the fact that light spreads so nearly in distinct straight lines, instead of diffusing itself all around as sound does, is an important difference.

"*Becoming less intense as it spreads.*" (See the Analysis, page 497.)

998. Any emanation from a central point, in spreading through wider space, becomes thinner or less intense in proportion as it spreads. Thus, if a taper be placed in the centre of a cubical box every side of which is a foot square, the light falling on the sides of the box, will have a certain intensity there:—if the taper be then placed in a similar box with sides of two feet square, there will be only the same quantity of light, but it will be spread over four times as much surface—for a square having two feet in the edge, is made up of four squares of one foot—and will, therefore, on any part of that surface, be only one-fourth part as strong or intense as in the first box:—and so for any other size of box or space, the intensity will diminish as the square of the distance increases. (See Art. 26.)

Hence four times as much light and heat fall upon a foot of this earth's surface at its actual distance from the sun, as if it were twice as far off beyond the planet Mars, just as four times as much light and heat fall on a man placed two yards from a fire, as on another who is distant twice as far.

"*Falling on other bodies makes them visible.*" (Read the Analysis, page 497.)

999. If the window-shutter of an apartment be perfectly closed, an eye present turns upon an absolute blank: it perceives nothing. If a beam of the sun be then admitted, and be made to fall upon some object, that object becomes bright, and affects the eye almost as if it were itself luminous. It returns a part of the light which falls upon it, and it is visible in all directions, proving that it scatters the received light all around and nearly uniformly. This scattered light, then, falling on other objects, and reflected again and again among them until absorbed—like echo repeated many times and lost between perpendicular rocks,

makes all of them also visible, although in weaker degrees, and the whole apartment is said to be lighted. If the direct ray be made to fall upon a thing which from its nature reflects much of the light, as a sheet of white paper or a mirror, the apartment will be more lighted:—if, on the contrary, it be received on black velvet, which returns hardly any light, the apartment will remain nearly dark. When the ray is received on a polished surface or mirror, which returns nearly the whole light, but only in one direction, and therefore throws it upon some other single object, the effect will be according to the nature of that object, and nearly as if the beam had fallen directly upon it.

1000. Now all bodies on earth, and among these the constituent particles of the mass of atmosphere surrounding the earth, retain and diffuse among themselves, for a time, the light received directly from the sun, and by so doing, maintain everywhere that mild radiance or luminosity agreeable to the sight, which renders objects visible when the sun's direct rays do not fall upon them. But for this fact indeed, all bodies shadowed from the sun, whether by intervening clouds or by any other more opaque masses, would be perfectly black or dark; that is, totally invisible. Without an atmosphere, the sun would appear a round intensely luminous mass in a perfectly black sky. On lofty mountain summits, where half the atmosphere is below the level, the direct rays of the sun are painfully intense, and the sky is by contrast dark.

1001. A shadow is the name given to the comparative darkness of places or objects, which are prevented by intervening things from receiving the rays of some luminous source shining on the things around. And the apparent darkness of a shadow, is not proportioned to its real darkness, but to the comparative strength of the surrounding lights. A landscape may be clearly seen, even when the sun is veiled by a cloud, and then little or no shadow is anywhere perceived; but as soon as the cloud passes away, deep bright lights appear where direct sunshine falls, and shadows behind every object which the direct sunbeam does not reach. Yet the objects and places then appearing dark, are in reality more illuminated than before the shadow existed, for they are receiving, and again scattering, new light from all the more intensely-illuminated objects around them. A finger held between a candle and the wall, casts a shadow of a certain intensity; if another candle be then placed in the same line from the shadow, the shadow will appear much darker, although in fact more light will be reaching it and reaching the eye from it than before: it will be darker only by comparison. If the candles be separated a little sideways, so as to produce two shadows of the finger, but which coincide or overlap in one part, that part will be of double darkness, as compared with the remainders. A common mode of comparing the intensity of lights is to place them at such distances from a screen or wall, as to make them at the same time throw on the screen equally dark shadows of the same intervening object; and then, according to the law of decreasing intensity explained above, to calculate the intensities of the sources of light by the difference of their distances from the wall. The eye judges very correctly of the intensity of shadows so compared.

1002. The real darkness of a shadow, then, depends much on the extent and nature of the light-reflecting surfaces around it. Thus, shadows are less deep opposite to any white surface than in other situations. An invalid lying in bed with back to the light may be saved the trouble of turning, to show the countenance, by a sheet of white paper held up to act as a mirror. The reason why the moon when eclipsed, that is, as will be afterwards explained, when passing behind the earth, through the shadow cast by the earth in a direction away from the sun—becomes almost, if not quite invisible, is, that there are no other moons or bodies near our moon to reflect their light towards it. And the reason why moonless nights on earth are darker than the shadows behind a house or rock in the sunshine of day, is merely that there are then no other great bodies near the earth to reflect light into its shadow, as there are other houses and rocks near to illuminate the day-shadow of these. The moon is the only light-reflecting body of magnitude which the earth has near it; and we perceive how much less dark the earth's night-shadow is when the moon is in a position to bear upon it.

Many persons have doubted whether the light of the moon could be, as astronomy teaches, altogether reflected light of the sun; the moon appearing to them so much more luminous than any opaque body on earth merely exposed to sunshine. They judged the so-called "lamp of night" to be as naturally self-luminous as "the lamp of day." Their error was in contrasting the appearance of the moon while receiving direct sunshine with that of objects on the surface of this earth, then in the darkness of the earth's shadow, which we call night. The moon when above our horizon in the day-time, is always visible from the earth to those who look for it, and is then throwing towards the earth just as much light as it does during the night; but the day-moon does not appear more luminous to human sight than any small white cloud of the same apparent breadth, so that, although visible in some part of every day except near what is called the change of moon, many persons have passed their lives without noticing it, as might happen with respect to a candle burning in the open air at noon. The full moon gives to the earth only about a one-hundred-thousandth part as much light as the sun.

"*Light moves with great velocity.*" (See the Analysis, page 497.)

1003. The extraordinary precision with which the astronomical skill of modern times enables men to foretell the times of remarkable occurrences or changes among the heavenly bodies, has served for the detection of the fact, that light is not an instantaneous communication between distant objects and the eye, as was formerly believed, but is a messenger which requires time to travel:—and the rate of the travelling has been ascertained. The eclipses of the satellites or moons of the planet Jupiter had been carefully observed for some time, and a rule was obtained which foretold the instants in all future time when the satellites should glide into the shadow of the planet, and disappear, or were again to emerge into view. After a time it was found, that these appearances took place 16½ minutes sooner when Jupiter was near the earth, or on the same side of the sun with the earth, than when it was on the other side, that is to say, more distant from the earth by the diameter of the earth's orbit; and at all intermediate situations the difference diminished from the 16½ minutes, in exact proportion to the diminished distance. This proved that light takes 16½ minutes to travel across the earth's orbit, and 8¼ minutes for half that distance, or to come to us from the sun.

1004. The velocity of light, ascertained in this way, is so marvellous (about 190,000 miles in a second), that the philosophic Dr. Hooke, when the assertion was first made, said he could more easily believe the passage to be absolutely instantaneous, even for any distance, than that there should be a progressive movement so prodigiously rapid. The truth, however, is now put beyond doubt by numerous other facts bearing upon the subject.

1005. As regards all phenomena upon earth, they may be considered as happening at the very instant when the eye perceives them; the difference of time being too small to be appreciated. It is hence usual and not sensibly incorrect, when we are measuring the velocity of sound, by observing the time between the flash and the report of a cannon fired, to assume that the event takes place at the very moment when the eye notes it. The speed of light and of the electric impulse are found to be nearly the same, and the public mind is now familiar with the prodigies of the electric telegraph.

"*Light proceeds in straight lines,*" *&c.* (Read the Analysis, page 497.)

1006. The conception of a straight line of light presents itself readily to one looking at a beam of light, entering by a small aperture a dark room, in which fine dust is floating and seen there as a line of "motes in the sunbeam." Other straight lines are, a thread supporting a weight, a cord stretched between fixed points, as used by masons in building straight walls, and by gardeners in making straight borders. A natural straight line in a solid body is exhibited in the edge of any crystal. An artificial example is the edge of a flat wooden ruler when made to coincide with a stretched thread.

1007. We can see through a straight tube, but not through a crooked one. The vista through a long straight tunnel is a striking illustration of this fact, as also of the diminution of the apparent size of objects as they are more distant. If a person enter a straight canal-tunnel two miles long, like that cut through the chalk hill between Gravesend and Rochester to join the Thames and Medway rivers (now converted into a railway), the opening at the distant end is clearly seen as a small luminous speck, having the exact form of the general arch.

In taking aim with gun or arrow, one is merely preparing to make the projectile go to the desired object nearly by the path along which the light comes from the object to the eye.

A carpenter looks along the edge of a plank, &c., to see whether it be straight.

Because light moves in straight lines, if a number of similar objects are placed in a straight line or row from the eye, the nearest one hides the others. In the middle of a wood or a city, a person sees completely only a few of the trees or houses that are nearest to him.

He who believed that a squinting person could see round a corner, erred as much as if he had thought that a crooked gun could shoot round a corner.

1008. All astronomical and trigonometrical observations are made on the faith of straight motion being a property of light, the observer holding that any object is situated from him in the direction in which the light comes to him from it. When the mariner, after watching for hours in cloudy weather, obtains certain views of the sun or a known star, through his angle-measuring instrument, he has ascertained his place among the trackless waves, and boldly advances although near unseen dangers. And the beam shot from a lighthouse across a stormy sea, would be useless if the light moved not in a straight line.

"*Leaving shadows where it cannot fall.*" (See the Analysis, page 497.)

1009. *The form of shadows* proves that light moves in straight lines, for the outline of the shadow corresponds correctly with that of the object as seen from the luminous body.

The shadow of a face on the wall is a correct profile.

A wheel presented edgeways to the eye appears only as a broad line, but it seems oval or round as it is otherwise turned; so a wheel presented edgeways to the sun or other light, casts at first a straight shadow on a wall behind it, and the shadow becomes oval or round as the position is changed.

A globe, a cylinder, a cone, and a flat circle, will all throw the same round shadow on a wall if held with their axes pointing to the luminous body, and therefore by the shadow only, these objects could not be distinguished.

The figure of a rabbit accurately cut in pasteboard, may throw the same shadow on a wall as the animal itself; and a similar shadow may be made by a certain position of two hands joined, as is known to those who find pleasure in witnessing the surprise and delight of a child who beholds such a shadow mimicking the actions of the living animal.

A man under the vertical sun, as may be seen near the equator, stands at noon upon his own little round shadow; but as the sun declines in the afternoon, the shadow juts out on the opposite side, and at last may extend across a field.

A distant cloud, which appears to the eye of an observer on the ground only as a streak along the sky, may yet be broad enough to shadow a whole region; for clouds generally form in level strata, and when viewed by a spectator on the ground at a distance are seen nearly edgeways.

The velocity of the wind may be ascertained by marking the time which the shadow of a cloud takes to pass over a field or any space of known dimension.

1010. A body held between a source of light and a wall, not only darkens a portion of the wall, or casts its shadow there, but makes the whole space between it and the wall a shadowed space, so that any object introduced there is as much shadowed as the portion of the wall. A striking illustration of this is afforded when a flock of white pigeons in sunshine wheel round a tall steeple. At the moment when they enter the shadow of the steeple they seem to vanish, although there is nothing in the air between them and the eye of the spectator. Thus, also, all the planets as they revolve about the sun cast a long shadow beyond them or away from the sun, and when one of their satellites or moons passes where the shadow is, it suddenly disappears. The satellites or moons of Jupiter, when they suddenly disappear from the field of view of our telescopes, or are eclipsed as we term it, have generally only plunged into the shadow of the planet, and are not hidden from us by being then on the other side of its body, as many persons suppose. When our own moon is eclipsed,—a phenomenon so awful to men in the early ages of the world, she is only passing through the long shadow which the earth casts beyond itself.

1011. In the case of a light-giving centre being broader than the object which casts a shadow, the shadow is less broad than the object, and terminates in a point. In the contrary case, the shadow is larger than the object, and still larger as the distance from the object is greater. When our moon passes between this earth and the broad sun, producing a total eclipse of the sun where its shadow falls, the band over which the shadow passes has to be computed, and is stated in the almanacs. Knowledge of the comparative sizes of the two globes gives the power of predicting what is to happen. The shadow of a hand held between a broad fire and the wall is small; and a small pasteboard figure of a man placed near a narrow centre of light, throws a shadow which is gigantic.

1012. When the surface which receives a shadow is oblique to the direction of the light, the shadow may be much longer or broader than the object, even when the sun is throwing the light;—as is seen when a narrow projecting roof, or a veranda, shadows from the high sun of summer noon the whole front of a house; or, as is proved by the long morning and evening shadows of trees, houses, men, &c., on the ground in all countries.

> "*Light passes readily through some bodies—which are therefore called transparent; but when it enters or leaves their surfaces obliquely its course is bent.*" (Read the Analysis, page 497.)

1013. It may well excite the surprise of inquirers, that light, of which the constitution is so subtile or unsubstantial, should still be able to dart readily and in every direction through great masses of solid matter, but such is the truth. Thick plates of glass, blocks of rock crystal, mountains of ice, &c., are at once pervaded by the beam of the sun.

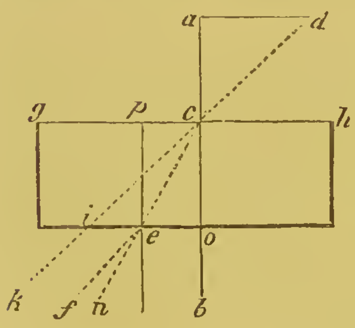
1014. What it is in the constitution of one mass as compared with another, which fits the one to transmit light, and the other to obstruct it, we cannot yet explain, but we perceive that the arrangement of the particles of the mass has more influence than their peculiar nature. Nothing is more opaque than masses of the metals, but all these become quite transparent when dissolved in an acid, or crystallized in the form of neutral salts, or when forming part of a coloured glass.

1015. It is to be remarked, however, that no substances are absolutely opaque and none perfectly transparent. Gold itself, which is one of the densest things, when hammered into very thin leaf, allows a feeble green light to pass through, and the purest water and air arrest a part of the light which enters them. A depth of twenty feet of pure water intercepts nearly half of the light which enters it; and of the sun's light when passing slantingly through a great extent of atmosphere, as shortly after sunrise or before sunset, a considerable portion is absorbed and lost.

1016. Light having once entered any transparent mass of uniform or homogeneous nature, passes forward in it as straightly as in a vacuum; but at the surface, whether on entering or leaving it, if the passage be oblique, and if the mass be of a different density or nature from the other transparent medium in contact with it, a very curious and most important phenomenon occurs, namely, the light suffers a degree of bending from its previous direction, proportioned to the obliquity. Such bending is technically called *refraction.*

1017. But for this fact, which to many persons might at first appear a matter of regret, as preventing the correct vision of objects through transparent media, light would have been of comparatively little utility to man. There could have been no simple converging lenses, as now, serving as helping spectacles to aged sight, nor any of the more powerful optical instruments, of which lenses form a part, as telescopes and microscopes; and not even the all-precious eye itself, of which the important part is the so-called crystalline lens.

1018. Light falling from the air directly or perpendicularly upon a surface of water, glass, or any such transparent body, passes through without suffering the least bending. A ray, for instance, shot from the point *a* in the air to the point *c* in the surface of a piece of glass *g h*, would reach directly across to the points *o* and *b*; but if the ray fall slantingly or obliquely, as from *d* to *c*, then instead of continuing straightly in its first direction to *i* and *k*, it is at the moment of its entrance bent downwards into a path *c e*, nearer to the line *c o*, called the perpendicular to the surface at the point of entrance—and then moving straightly while in the substance of the glass, it would, when passing out again at *e*, in the opposite surface, be bent just as much as at first, but in the contrary direction, or away from the perpendicular at that surface, *viz.*, into the line *e f* instead of *e n*. A ray therefore passing obliquely through a transparent body with parallel surfaces, has its course shifted a little to one side of the original course, but still proceeds in the same direction, or in a line parallel to the first—as here shown in the line *e f*, parallel and near to the line *i k*. If the surfaces of the transparent body are not parallel to each other, the ray is otherwise bent, as will be explained in coming pages.



1019. The degree of the bending or refraction of light in penetrating obliquely a transparent surface is measured by comparing the angle of obliquity of its approach to the surface, called *the angle of incidence d c a*, with that of the obliquity of its departure beyond *e c o*, called *the angle of refraction*, and for this purpose a line is supposed to be drawn perpendicularly through the surface at the point where the ray enters (as *a b* in the above figure drawn through *c*), and the relative positions of the ray to this line, or the angles formed at their meeting both above and below, are easily ascertained. Thus the line *d a*, drawn from a point of the ray before passing to such perpendicular, is a measure of the original obliquity or angular distance of the ray, and is called the *sine of the angle of incidence*, and the other line *e o* drawn from an equally distant point of the ray after passing to the same perpendicular, is a measure of the obliquity after refraction, and is called the *sine of the angle of refraction*:—by comparing these two lines in any case, the problem is solved. (See the mathematical Appendix.)

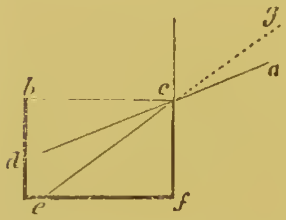
1020. When light passes obliquely from air into water, the refraction or bending produced is such, that the line *a d* measuring the obliquity before refraction, is always longer than the line *o e* measuring it after refraction, as the number four to three, and the refracting power of water is therefore signified by the index $\frac{4}{3}$; in like manner, the greater refracting power of common glass has the index $\frac{3}{2}$, and so on, for other substances. And it is important to remark, that for the same substances the same relation always holds whatever the obliquity of the incidence may be. If, for instance, as in the passage from air to water, where the obliquity of the incident ray, as measured by its *sine*, is 40, that of the refracted ray will be 30.

1021. As a general rule, the refractive power of transparent substances or media increases with their densities. It increases, for instance, through this list,—air, water, salt, glass, &c. But Newton, while engaged in his experiments upon this subject, observed that inflammable bodies had greater refractive power than others, and he then hazarded the conjecture, of singular sagacity, which chemistry has since so remarkably verified, that diamond and water both contained inflammable ingredients. We now know that diamond is merely crystallized carbon, and that water is composed of hydrogen or inflammable air and oxygen. Diamond has the greatest light-bending power of any known substances, and owes to this in part its brilliancy as a jewel.

1022. An explanation to aid popular conception of the singular fact of refraction has been offered, namely, that it occurs because of an attraction between the light and the refracting denser medium. The light approaching from *d* to *c*, for instance (in the last figure), is said to be attracted by the solid body below it, so as at the surface to be bent into the direction *c e*; and, again, on leaving the body, is still equally attracted and bent back again, so as to take the direction *e f*, instead of *e n*; the attraction and bending being greater, the greater the obliquity.

1023. The following are familiar examples of this bending of light in passing from one medium to another.

If an empty vessel *b c f e*, be in the sun's light, so that the rays falling within it may reach low on the side, as from *a* to *d*, but not to the bottom, then, on filling the vessel with water, the sun will be found to be shining on the bottom or down to *e*, as well as on the side. The reason of this phenomenon is, that water being a denser and more refracting medium than air, the light on entering it at *c*, is bent towards the perpendicular (*c f*), at the point of incidence, and reaches the bottom. So again, if a coin or pebble were laid on the bottom of such a vessel at *e*, it would not, while the vessel were empty, be seen by an eye at *a*, but would be visible there immediately on the vessel being filled with water; for then the light leaving the coin in the direction of *e c*, towards the edge of the vessel, would at *c*, on passing from the water into air, be bent away from the perpendicular, and instead of going to *g* would reach the eye at *a*. The coin, moreover, would appear to the eye to be in the direction *c d*, higher up, instead of in the true direction *c e* low down: for the eye not being able to discover that the light had been bent in its course, would judge the object to be in the line by which the light arrived.



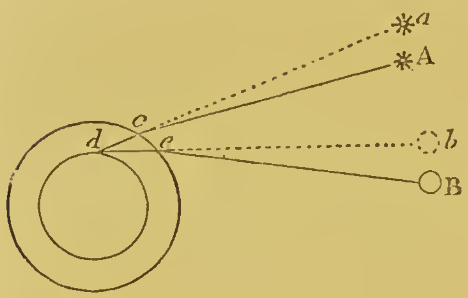
1024. It is thus because objects at the bottom of water, when viewed obliquely, do not appear so low as they really are, that a person viewing the bottom of a river or pond, or any clear water from its bank, naturally judges its depth to be much less than it really is. Many a young life has been lost from this illusion. A person, if looking from a boat directly down upon objects at the bottom of water, sees them in their true directions, but even then not quite at their true distances, as will be afterwards explained; but if he view them more and more obliquely, the appearance becomes more and more deceptive, until at last it may represent them as being at even less than half of their true depth.

An incident witnessed by the writer in early life may be mentioned in illustration. In crossing the China Sea, where no danger was apprehended, an alarm was suddenly given that the ship was among rocks. Through water singularly clear, coral rocks were visible all around and at no great distance; some of them seemed to approach the surface of the water. The sails were instantly backed and soundings were taken, which proved the depth to be greater than appeared, but which directed an altered course, and the ship was soon in deep water again.

On account of this bending of light from objects under water, there is more difficulty in hitting them with a bullet or spear. The aim by a person not directly over a fish must be made towards a point apparently below it, otherwise the weapon will miss by flying too high. The spear sometimes used in this country for killing salmon, is a weapon employed among the islanders of the Southern Ocean for killing the albacore; the use of it, like that of the fly-hook in England, affording to the fishermen sport as well as profit. The writer witnessed this at St. Helena. A small fish was at intervals thrown upon the water as a bait, in the sight of albacores below. Some one of them soon made at the mouthful with remarkable speed, but which yet did not always give safety, for every now and then the thrown spear struck the fish.

1025. The bending of light, when passing obliquely from water, explains the following facts. A straight rod or stick, of which a portion is immersed obliquely in water, appears crooked at the surface of the water, the portion immersed seeming to be bent upwards. That part of a ship or boat visible under water appears much flatter or not so deep as it really is. A deep bodied fish seen near the surface of water, appears almost a flat fish. A round body there appears oval. A gold fish in a vase may appear at the same moment as two fishes, being seen both by light bent through the upper surface of the water, and by straighter rays passing through the side of the glass. To see bodies under water, in their true directions and nearly of their true proportions, the eye must view them through a tube, of which the lower end, closed with plate-glass, is held in the water or through the upright sides of containing vessels formed of plate-glass, now common in zoological gardens.

1026. As light is bent or refracted on entering obliquely from air into water, glass, or other substance denser than air, so also is it bent on coming from void space into the ocean of our atmosphere. Hence none of the heavenly bodies, except when directly over our heads, are seen by us in their true situations. They all appear a little higher than they really are, and more so the nearer they are to the horizon. To a spectator at *d* supposed to be on the surface of the earth, a star really at A appears to be at *a*, because its ray, on reaching the atmosphere at *c*, is bent downwards. In astronomical books there is always given a table of refractions, as it is called, showing what correction must be made on this account for different apparent altitudes. This effect of our atmosphere so bends the rays of the sun that we see him in the morning a little while before he is really above the horizon, and we see him in the evening a little while after he is really below it, for the ray coming horizontally from *e* to *d* appears to come from *b*, although in truth it comes from the lower situation B, and is bent into the level line only at *e*. Our atmosphere thus, by the bending of light as well as by itself becoming luminous (Art. 1001), lengthens at dawn and twilight the duration of the precious day. As the atmosphere is denser near the surface of the earth than higher up, the light is more and more bent as it descends, and hence describes a course which is gently curved, and therefore unlike the course of light in incompressible water.



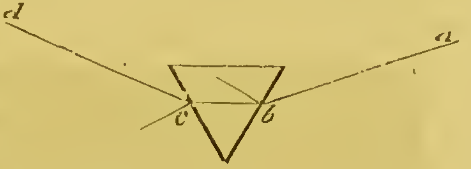
Certain states of the atmosphere, depending chiefly on its humidity and warmth, change very considerably its ordinary refractive power; hence, in one state a distant hill or island may be just visible over an intervening eminence of land, and in other states the same object will be seen high above, or may have altogether disappeared, in the latter case, as if the bed on which it rested had sunk deeper into the earth.

1027. Owing to the bending of light when passing through media of different densities, an interesting phenomenon is often observable in a day of warm sunshine. Black or dark-coloured substances, by absorbing much light and heat from the sun's rays, warm the air in contact with them, and make it dilate and rise in the surrounding air, as oil rises in water. The light then from more distant objects, reaching the eye through the rarefied medium is bent a little; and owing to the heated air rising irregularly under the influence of the wind and other causes, many objects seem to have a tremulous or a dancing motion. The same phenomenon is to be observed at any time, by looking at an object beyond the top of a chimney from which hot air without smoke is rising.

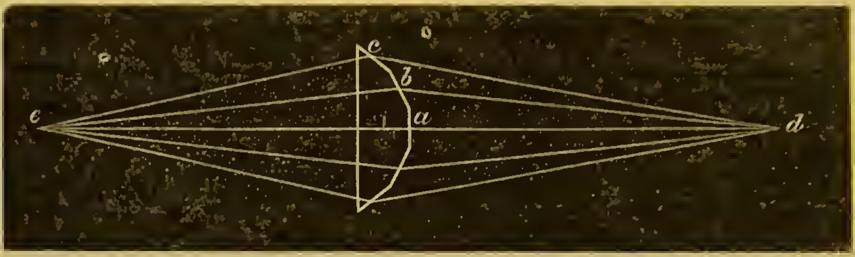
This bending of light by the varying states of the atmosphere renders necessary the frequent repetition of geometrical observations made in the measuring of heights or of base-lines for the construction of maps and charts.

1028. As it is the obliquity with which a ray traverses the surface, which in any case of refraction determines the degree of bending, a body seen through a medium of irregular surface appears so distorted as not to be recognisable. It is because the two surfaces of ordinary window-glass are not, as in the case of plate-glass, perfect planes, and parallel to each other, that objects seen through a common window appear generally more or less out of shape. Hence the beauty and utility of plate-glass windows, now coming into general use.

1029. The refraction or bending of light is most interestingly exemplified in the effect of the glass called a prism. It is a straight three-sided rod of glass, such as that of which the end or cross section is here represented at *b c*. A ray from *a* falling on and entering the surface at *b* is there bent *towards* the internal perpendicular, and in consequence reaches *c*, then on escaping again at *c*, it is bent *away* from the external perpendicular, and thus with its first deviation doubled goes on to *d*.

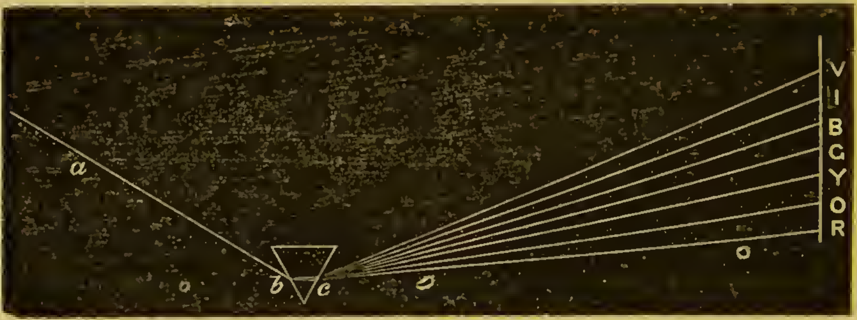


1030. The law of light's bending according to the obliquity with which it traverses the surfaces of a transparent body, is well elucidated by the effect of what is called a multiplying glass, that is to say, a flat piece of glass, *a b c f*, having many distinct faces cut upon it at angles with each other. If any small object, a coloured bead for instance, be placed at *d*, an eye at *e* will see as many beads as there are distinct surfaces or faces on the glass; for first, the light *d a* passing perpendicularly, and therefore straight through, will form an image as if no glass intervened; then, the rays from *d* to the surface *b* will be bent by the oblique surface, and will show the object as if it were in the direction *b e;* and the light falling on the still more oblique surface *c*, will be still more bent, and will reach the eye in the direction *c e*, exhibiting a similar object also in that direction—and so of all the other surfaces. If the eye were at *d*, and the object at *e*, the result would still be the same. A plate of glass roughened, or cut into cross furrows, becomes an effectual screen or window-blind, by disturbing the passage of light through it so that objects beyond it are not distinguishable.



> "*And a beam of white light thus made to bend very much is resolved into beams of the seven so-called primary colours seen in the rainbow; which beams on being again collected and blended, become white light as before.*" (Read the Analysis, page 497.)

1031. The very singular fact connected with the bending or refraction of light is, that a beam of pure white light from the sun admitted into a darkened room by a small opening in the window-shutter, and made to bend by passing through transparent surfaces which it meets very obliquely (as the beam *a*, admitted and made to bend by passing through the prism of glass *b c*, to fall upon the wall at *d*), instead of bending all together and appearing still as the same white light, is divided into many beams, which falling on the white wall, are seen to be of different most vivid colours. This solar spectrum, as it is called, formed upon a screen, consists of seven distinct coloured patches appear-



V, Violet. I, Indigo. B, Blue. G, Green. Y, Yellow. O, Orange. R, Red.

ing in the order shown above, with red the least bent or refracted colour below, the orange next, then the yellow, and so forth. The orange between the red and the yellow seems to be a mixture of the two, as the green seems to be of the yellow and blue. It was soon found that if these seven colours which appear in the spectrum were painted separately round the rim of a wheel, and the wheel were then turned rapidly, the individual colours ceased to be distinguished, and only a white band appeared where they were whirling: also that if the rays of the spectrum produced by a prism be again gathered together by another prism reversed, or by a lens, they reproduce white light as before.

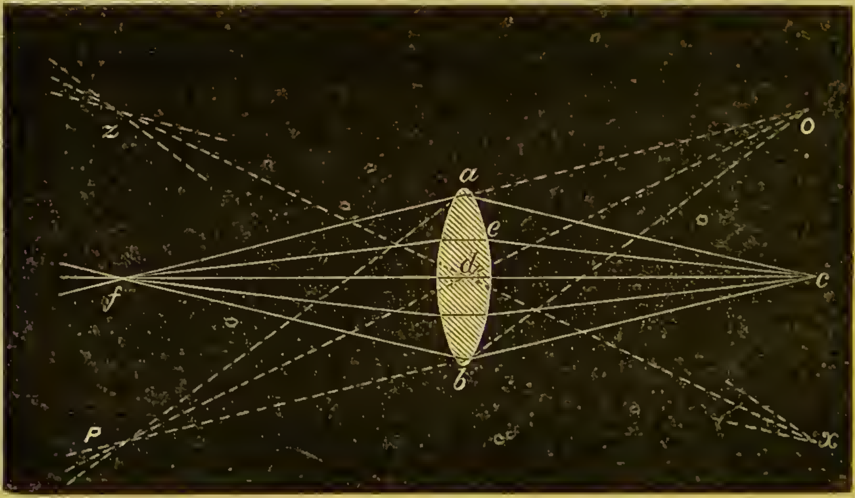
1032. When Newton first made known the phenomenon of the many-coloured spectrum, and some of the extraordinary conclusions to which it led, great surprise was universally excited, for the common conception of purity the most unmixed, was that of white light. Subsequent researches, some of them very recent, and some now only in progress, have discovered other influences connected with the sunbeam not less important than its light. It is ascertained that much of the heat of the beam is still less refracted than even the red light; for a thermometer held below the red patch in the spectrum where there is no light, rises higher than in any part of the visible spectrum; and there is an invisible influence in the beam more refrangible than even the violet rays, but partly combined with some of the colours, which is capable of producing powerful chemical effects on inanimate matter, as is proved in the art of photography, and in physiological effects on living vegetables and animals.

1033. All transparent substances, when bending light strongly, produce more or less of the separation of colour; but it is an important fact, that the quality of merely bending a beam, or of *refraction,* and that of dividing it into coloured beams, or of *dispersion,* are distinct qualities, not having the same proportion to each other in different substances. Newton, from not being aware of this, concluded that a perfect large telescope of refraction could never be made: he assumed that the bent light would always become coloured, and so, would render the images indistinct. We now know, however, that by uniting lenses of two or more kinds of glass, we may obtain the requisite bending of light without dispersion. This very important discovery was made by the eminent optician Dollond, the first maker of the achromatic telescope.

1034. The diversified colours of the substances in nature depend upon their fitness, from texture or other peculiarity, to reflect or transmit certain modifications of common light; the different colours not being parts of the body itself. We have to explain in a future page that the vivid colours of the rainbow are merely the white light of the sun, reflected to us after being refracted and modified by the transparent drops of falling rain, and that the sparkling with appearance of rubies and emeralds, which we see in a cut-glass lustre, is a phenomenon of the same kind:—and we shall learn that by scratching the surface of a piece of metal so as to have a different given number of lines in a given space, as mother-of-pearl shell has, we can cause the same substance to appear of different colours.

> "*To transparent substances, as glass, such form may be given as to cause all the rays of light which pass through them from any one point, to bend so as to meet again in another corresponding point beyond them and pass onwards,—the body itself, from the required shape generally resembling that of a flat bean or lentil, being then called a* LENS." (Read the Analysis, page 497.)

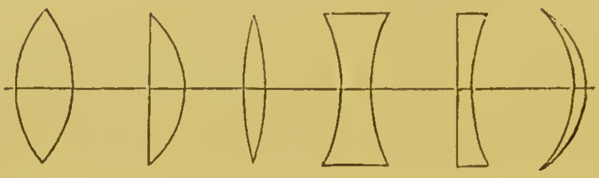
1035. The innumerable rays of light (of which five only are here represented), issuing from any point at *c*, towards any surface in the situation *a b*, are said to form a cone or pencil of diverging light. It is evident that to make all such rays converge or meet again in one place, as *f*, beyond a transparent body placed at *a b*, it would be necessary, while the middle ray or axis of the pencil *c d f* did not bend at all, for the others to be bent more and more, in proportion as they fell upon the body



farther and farther from the centre *d*. Recollecting then the law of refraction, that light entering from air through the surface of a denser medium, as glass, is bent there towards the perpendicular at the internal surface, in proportion to the obliquity of incidence, and on leaving the opposite surface, is correspondingly bent away from its external perpendicular (see the case of the prism, Art. 1029), we see that if a piece of glass were placed at *a b*, of such form that the rays falling upon it from *c* should meet and leave its surfaces with greater and greater obliquity in some regular proportion, as the points of incidence were more distant from the centre *d*, the purpose would be obtained. And we have the satisfaction of knowing that a glass of which the surface is ground—which, as in common spectacle glasses, it easily may be—to have a regular convexity or bulging, as if it were a portion cut off from the surface of a ball or sphere, can be shown to possess very correctly the required condition. Such a glass, similarly ground on both sides, is here represented in section, edgeways, between *a* and *b*, where the ray *c d* falling on its middle, perpendicularly, and similarly leaving it, is seen going straight through to *f*; but the ray *c e* meeting the surface with a certain degree of obliquity, is bent down a little, first on entering the surface at *e*, and then as much more on leaving the opposite surface with equal obliquity, and so arrives at *f*; then the ray *c a*, for corresponding reasons, is still more bent, and equally arrives at *f*;—and the case would be similar of any other rays that might be examined. The point *f* is usually called a *focus* (the Latin for *fire-place*), because when the light of the sun is thus gathered, the heat concentrated with it is powerful enough to set combustibles on fire.—We have here to remark farther, that in accordance with both calculation and experiment, the direction in which a whole pencil of rays falls upon a lens does not affect the result of the convergence to a focus, which focus, however, is always in the direction of the central ray of the pencil or beam; it will be at *p*, for instance, for light issuing from *o*, and at *z* for light issuing from *x*, and at corresponding focal points for the rays from every point of any object in the light. It is important to understand here that rays of light meeting at any focal point in the air or in other transparent medium, do not at all disturb one another like solid masses clashing, but simply cross and pass onwards, as sketched here at letters *z f p*.

1036. The lens represented at *a b* above, or in the annexed diagram, at fig. 1, having both sides convex, is called *a double convex lens.* A glass convex only on one side, and plane or flat on the other, as shown at fig. 2, does as effectually gather the rays, but with half the power, and the point of meeting or focus is therefore proportionately more distant. Such a glass is called a *plano-convex lens.* Then the gathering or converging power of any glass, whether doubly or singly convex, is in proportion to the degree of its convexity or the bulging of the surfaces, for the less it bulges, the more nearly does it approach to being a plane glass, and the more it bulges, the more obliquely will the rays, at any distance from the centre, fall upon its surface, and the sooner, therefore, in consequence of their being more bent, will they all meet the axis-ray to form a focus;—hence fig. 1 would converge much more quickly than fig. 3, which represents nearly a common spectacle glass; and a very minute globe is the form most powerfully converging of all. The surfaces of fig. 1, are portions of a small globe; those of fig. 3 are smaller comparative portions of a globe much larger. Concave lenses, as fig. 4, which is a double concave, and fig. 5, which is a plano-concave lens, in obedience to the same law of refraction, spread rays, or bend them away from the axis of the pencil, in the same degree that similarly convex lenses gather them. A concave lens, therefore, receiving the converging pencil of rays from a convex lens, might restore them to their former nearly parallel direction. Very useful purposes, as will be afterwards explained, are served in optics, by certain combinations of differently formed lenses. A lens may be convex on one side and concave on the other, as at fig. 6, called a meniscus lens, because it resembles the crescent moon, and its effect will be according to the curve which predominates.

Fig. 1 2 3 4 5 6

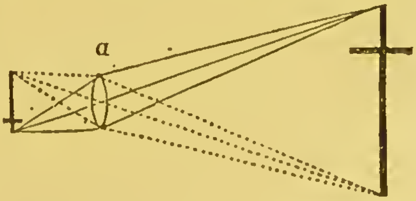


1037. A person recollecting the case of the "multiplying glass," described at page 514, might say,—but is not a convex lens merely a multiplying glass of a much greater number of faces, and if so, why, instead of one image, does it not make thousands? The answer is, that the multiplying glass, by every face, bends *a* *set* of rays, capable of forming a distinct and complete image; but the lens has no surface large enough to bend more than single rays, it concentrates all into focal points, which form a general image of great vividness and beauty.

> *"And when the light proceeding towards a lens from every point of an object placed before it is collected in corresponding points behind it, a perfect image of the object is there produced. When the image is received upon a suitable white surface, in a dark place, the arrangement is called, according to other circumstances, the* CAMERA OBSCURA, *the* SOLAR MICROSCOPE, *or the* MAGIC LANTERN." (Read the Analysis, page 497.)

1038. It is common knowledge that a sunbeam entering a room by an opening in a window-shutter makes a bright patch of light on the opposite wall, which travels slowly east as the sun travels west, and which is high while the sun is low, and lower as the sun rises higher. Similarly at night, if a lantern be carried past such a window, it produces a patch having position and motion the contrary always to those of the lantern. If the lantern be of coloured glass the patch will have more or less of corresponding colour. In the day-time, too, when every visible object is radiating reflected light all around it, every one in front of an open window is sending light in to the opposite wall; but the things being so numerous and with such differences of shape and colour, the rays all mix, and have the effect on the wall merely of what is called general daylight. By partially closing the window, however, in such a case, and employing a lens, such as above described, to occupy the aperture left, the great confusion is instantly converted in striking order.

1039. Language is wanting to express the momentous consequences to man of the power of a lens, above explained, which can bring together to focal points beyond it all the rays of light which traverse it from the points of an object placed before it. The following instance illustrates well. If a lens, such as a common spectacle glass, *a*, be placed to fill up an opening made in the window-shutter of a darkened room, then, from any object before that opening—as the cross here represented, all the light which different points radiate towards the lens will



be concentrated or gathered together in corresponding focal points behind the lens within the room, and if a sheet of paper be held there at the distance of the focal points, a beautiful inverted image of the object will be seen upon the paper.

1040. In these few words, we have described that most interesting arrangement called the *camera obscura* or *dark chamber;* and when a glass is chosen of proper size and focal distance, and a screen or the wall of the chamber (if at the required distance), is properly prepared to receive the light, the most admirable portraiture is instantly produced of the whole scene which the window commands. With what rapture does the schoolboy first view this enchanting picture drawn by nature's own pencil, with colours taken directly from the sun's bright ray! With what delight, as his eyes search over it, does he recognize, perhaps, his schoolmates at play, and the river in which he bathes, or sails his boat, and the wood in whose solitudes he loves to wander, and the mountain heights which he climbs to meet the fresh breeze, and to contemplate the wide expanse beneath him. The great peculiarity of such a picture is, that it does not, like others, portray still-nature, but every thing with appropriate motion or changes: the playmates are all in action; the leafy trees wave in the wind, the clouds sail along, the sun may rise or may set, and even the lightning's gleam may dart across; yet further, commenced enterprizes may be brought to a close; the traveller may climb the distant hill and disappear; the fisherman may draw his net and secure his gain; the contested race may be won or lost. A Malayan chief in the island of Sumatra, was so surprised and pleased by seeing a small portable camera which the author happened to have among his apparatus, that he thought it must be an object beyond all price.

1041. It appears in the last diagram that the image formed beyond a lens by the gathered light, is in a contrary position to the object itself,—that is, inverted,—for, the light from the top of the object darts through the opening or glass in a descending direction, and that from the bottom rises to the opening, and in the same direction passes beyond it. It is necessary, therefore, in a camera obscura, to place a small mirror diagonally behind the lens, so as to throw all the light which enters, downwards to a broad table, upon which the picture may be conveniently contemplated from any side.

The camera obscura gives useful assistance to young painters, by enabling them to study perspective outlines and the effects of light, shade, and colour, more profitably than they at first can, by looking at the objects themselves.

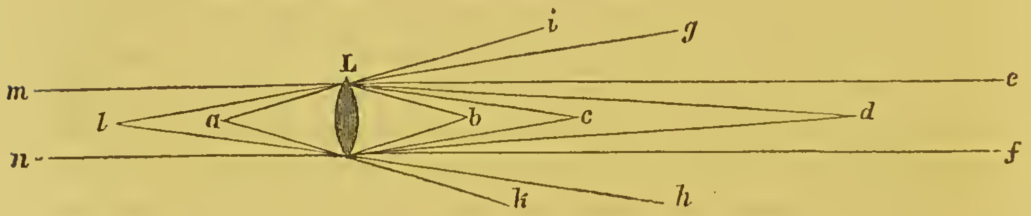
1042. While the pictures produced by the camera were admired as transcendently beautiful, there was ever regret that they were so transient, lasting only while the sun shone, or while the window was open. But wonder has followed wonder in the advance of art in this department; and now, by certain chemical preparation of the screen on which the imagery of the camera is to be formed, the admission of light for a few seconds gives a result as permanent nearly as solid colours on canvas. This new art is called *Photography* (writing by light), now much practised.

1043. An effect, approaching in a degree to that of the complete camera obscura now described, and already spoken of in Art. 1038, is produced by merely making a small hole in the shutter of a dark room, and letting the light which enters by it fall on any white surface beyond. The whole landscape is at once dimly portrayed upon the surface. Barry, the eminent painter, while lying on a sick bed, in fever, mistook such a scene appearing on the ceiling of his room for a supernatural vision. If a cross be held before the opening (see Art. 1039), it is evident that from every point of the cross light will enter by the opening, and will fall on corresponding parts of a sheet of paper held behind,—but as the light from each point is not a single ray, but a spreading pencil or cone of light, this will fall on the paper, not on one point, but on a surface larger than the opening, and the light from adjoining points will overlap and mix at the edges, and will render all the images misty and indistinct. If the opening be very small, the picture will be tolerably defined, but very feebly illuminated: and if the opening be of considerable size, the mixing of the pencils will be so great as to leave no particular object distinguishable. In either case, however, if a lens be introduced to fill the opening, it will converge every entering pencil of light to an exact point, and a perfect picture instantly starts into view.

1044. It is interesting to reflect that any lens, such as the two in a pair of spectacles, is never held up in the light without forming, on one side of it, such images as above described of all the objects on the other side—the images not being seen only because there are no screens placed to receive them, and no opaque enclosure made around them to exclude the light from other objects not desired to be seen. But even without such enclosure, if a pair of spectacles be held up at about a yard of distance from a lamp, candle, or fire, and white paper be held at the distance of about a foot on the other side of the lenses, clear inverted images of the objects are seen upon the paper. Even in daylight, paper held thus near a pair of spectacles, between them and the window, has on it inverted pictures of the window-bars, and of any striking objects in the sunshine outside.

1045. The distance from a lens at which an image is formed or the rays of the light meet, called the focal distance, depends, first, upon the refractive or bending power of the lens, that is, on its form and substance; and, secondly, upon the direction of the rays of light when they reach the lens, as to whether they are divergent, parallel, or convergent. We have already explained that glass refracts much more than water, and that diamond refracts much more than glass; and we have considered the effect of different degrees of convexity in lenses, whether the lens be of water inclosed between concave glasses like watch-glasses, or of solid glass, or of rock crystal, or of diamond itself. We now proceed to consider the joint effect of the refractive power, and of the direction of the incident rays.

1046. Rays diverging from a point *a*, to fall on a comparatively flat or weak lens at L, might meet only at the point *d*, or even further off; while, with a stronger or more convex lens, they might meet at *c* or at *b*. A lens weaker still might only destroy the divergence of the rays, without being able to give them any convergence, or to bend them enough to bring them to a point at all,—and then they would all proceed parallel to one another, as seen at *e* and *f*. If the lens were yet weaker, it might only destroy a part of the divergence, causing the rays from *a*, after passing through, to go to *g* and *h*, instead of to *i* and *k*, in their original direction.



In an analogous manner, light coming to the lens in the contrary directions from *b*, *c*, *d*, &c., might, according to the strength of the lens, be all made to come to a focus at *a* or at *l*, or in some more distant point; or the rays might become parallel, as *m* and *n*, and therefore would never come to a focus, or they might remain divergent.

It may be observed in the above figure, that the farther an object is from the lens, the less divergent the rays are which fall from it upon the lens; or the more nearly do they approach to being parallel. Proceeding from *b* there is much divergence in the exterior rays, from *c* less, from *d* less still, and rays from a great distance, as those represented by *e* and *f*, appear quite parallel. If the distance of the radiant point be very great, they really are so nearly parallel that a very nice test is required to detect the non-accordance. Rays, for instance, coming to the earth from the sun, do not diverge the thousandth of an inch in a thousand miles. Hence where we wish to make experiments with parallel rays, we take those of the sun.

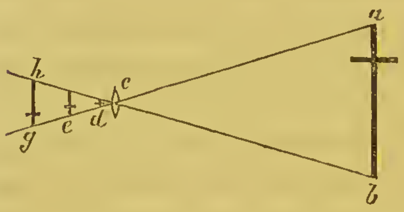
Any two points so situated on the opposite sides of a lens, as that when either becomes the radiant point of light, the other is the focus of such light, are called *conjugate foci.* An object and the image of it formed by a lens are always in *conjugate foci*, and as the one is nearer the lens, the other will be in a certain proportion more distant.

1047. What is called the principal focus of a lens, and by the distance of which from the glass we compare or classify lenses among themselves, is the point at which the sun's rays, or any parallel rays, are made by it to meet; and thus, by holding the lens in the sun, and noting at what distance behind it the little luminous spot or image of the sun is formed, we can at once ascertain the focus of a glass—as at *a* for the rays *e* and *f*.

It is a remarkable coincidence that the bending or refractive power of the common glass used for lenses is such, that the focus of a double convex lens is just as distant from it as the centre of the sphere, of which its surface is a portion. This gives another fact with which to associate the recollection that the focus is nearer as the convexity of the lens is greater, that is to say, as the surface is a portion of a smaller sphere. And such being the law, it may be proved by calculation agreeing with the fact, that if a candle be held in relation to a lens at twice the principal focal distance, suppose at *c* for a lens with the focus at *a*, the image of the candle will be formed at *l* just as far on the other side. Thus then, by trying with a lens until the image of a candle is formed at the same distance from it as that at which the object stands, we have a second mode of ascertaining the focal distance of a lens, or the degree of its convexity. Other kinds of glass and other substances refract with different power; but the facts now stated should be retained in the memory as standards of comparison.

1048. Because the focal point of light passing through a lens is at the same distance from the centre of the lens, in whatever direction the light passes through, a surface placed to receive the picture of a broad field should really be concave, that is to say, all parts of it should be nearly at the same distance from the centre of the lens, otherwise the image will be more perfect either at its middle than towards its edges, or the contrary—but it is not found necessary to attend to this in common practice, where the object and its image are not of great extent.

1049. The size of an image formed behind a lens is always proportioned to the distance of the image from the lens, and the image is as much larger or smaller than the object as it is farther from or nearer to the lens than the object is. This will be evident from considering the annexed figure. *C* represents the place of a lens, and the lens, according to its power, will form an image of the cross *a b* in some situation, as at *d*, *e*, or *g*, &c. Now wherever the image is formed, and by whatever lens, one end of it must be in contact with the line *a g*, and the other end with the line *b h*; and as these lines cross each other at *c*, and widen regularly afterwards, a line joining them (and the image is such a line), must always be shorter the nearer it is to *c*, that is to say, shorter in proportion to the converging power or focal distance of the lens.



1050. Many persons may not have reflected, that the narrow luminous circle called the focus of a burning-glass, is really but the image or picture of the sun formed by that glass or lens. The intensity of the heat and of the light is of course in proportion as the image is smaller than the glass which forms it, and the nearer that the image is formed to the lens, or the more powerfully convergent that the lens is, the smaller will the image be. Mr. Parker's famous burning lens, which cost £700, and became the property of the emperor of China, was three feet in diameter, and the diameter of the sun's image formed by it was one inch: it concentrated the light and heat therefore about 1,300 times. To render the effect still more powerful, a smaller lens was placed behind the larger, further reducing the size of the focal image. Surprising effects were produced by this lens, in the melting of metals, inflaming of combustibles, &c. The size of burning lenses, formerly, was limited by the difficulty of obtaining the great masses of glass required to form them; but glasses have since been built up of many pieces suitably united together. Some large lenses have been made of water, that is, of water inclosed between capacious glasses, formed like watch-glasses. A common spherical goblet of water, or a vase for holding gold-fishes, has in some cases acted as a burning-glass, setting fire to window-curtains, near to which it had been left in the sunshine.

1051. And the nearer that an object is brought to a lens, the more distant, and therefore the larger will the image formed by it become; for, as the rays falling upon a lens are divergent in proportion to the nearness of the object, and therefore with the same power of lens, must meet farther behind (as seen in the figure opposite), so the axes of the sets of rays, as the lines *c a* and *c b* in the last figure, will be separated farther before the rays meet, and will have made the image proportionally larger. If we suppose the cross *d* in the same diagram to be the object, its image would be *a b*. The sun is exactly as much larger than his image formed by a burning-glass, as he is more distant from it than the image; and if we had a screen of sufficient size hung up in distant space, any very bright object of a quarter of an inch diameter might be conceived to form by a lens an image as broad as the sun.

From all these considerations, it follows that, in a camera obscura, the screen should, for distant objects, be placed from the lens, at the distance of its principal focus, and a little farther off than this for near objects. Accordingly, the lens is usually fixed in a sliding piece, which allows the distance from the screen to be adjusted to circumstances. If the representation be desired large, the lens must be of a long focus; if small, the lens must be of a short focus. Again, when by the reversed use of the lens, a small object as *d* is to be magnified on a screen or in the air to such a size as *a b*, then the object must be placed but a little beyond the principal focus of the glass; if it be placed nearer, the pencils of rays from it would never be gathered to focal points at all, and no image would be formed at any distance.

1052. When, as supposed in the last sentence, a small object is placed very near a strong lens, and the image is thrown upon the wall of a dark room, perhaps a hundred times farther from the lens than the object is, the image is a greatly magnified representation of the object, viz., it is a hundred times longer and a hundred times broader, and therefore has ten thousand times as much surface as the object; but if in such an experiment the object be illumined only in an ordinary degree, the light from it is so scattered as not to suffice for distinct vision. Hence, to attain fully in this manner the purpose of a microscope, a very strong light, concentrated by a suitable mirror or lens, must be directed upon the object. When the light of the sun is used in such a case, the complete apparatus is called the *solar microscope*, and serves well to display the structure of many minute objects. When artificial light is used, as that of a lamp, the apparatus is called the *lucernal microscope* or *magic lantern.*

1053. The solar microscope was highly valued until the improvements in the construction of lenses were made, by which the dispersion of light, or the rainbow fringe was prevented, and until the electric light could be substituted for that of the sun. With the table microscope only one person at a time can see the wonder; but with the solar microscope, or that with the electric light, a whole roomful of company may be at once contemplating the same objects and witnessing the same actions.

1054. The magic lantern consists of a powerful lens, with objects, highly illumined by artificial light, placed so near it that their images are formed far off, and are therefore proportionally larger. For the magic lantern the objects are generally paintings made on thin plates of glass with transparent colours; and the plates are formed to slide in a groove behind the lens. The lens itself is moveable, because connected with the moveable tube which is seen projecting from the lantern, so that its distance from the object may be varied, and thus a corresponding approach to or receding from the screen is allowed, which will vary the magnitude of the visible picture on the wall.

Some public lecturers on astronomy and other branches of knowledge, have had the drawings and paintings required for the elucidation of their subjects, made in miniature upon glass, to be magnified to the degree desired, upon a screen in the lecture-room, by the magic lantern.

1055. A thin mist or smoke at night will sometimes reflect the images of a magic lantern so as to make them distinctly visible; and there are cases on record, where persons, mischievously ingenious in this way, have terrified ignorant individuals almost to death, by throwing spectres from a concealed lantern upon an artificially-produced smoke.

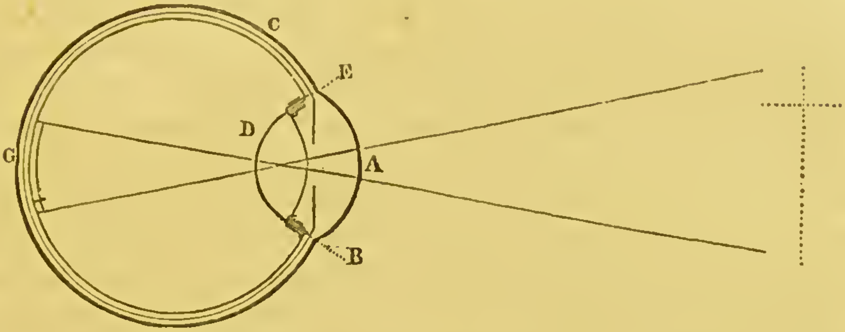
1056. *Dissolving Views.*—Under this appellation a very pleasing theatrical exhibition has of late become common. After the spectators are seated, the theatre is rendered for a little while completely dark, and pleasing music may be heard. Then there comes into view, over the stage, appearing a reality, some scene of high interest,—such as the Falls of Niagara, ships surrounded by the icebergs and cliffs of a polar region, a party of travellers laboriously working their way among precipitous rocks, over a high mountain pass, a numerous caravan traversing a sandy desert, &c. Suitable verbal description accompanies, and when time has been given for full examination of one scene, the sound of a little bell announces the coming change. The late view begins to fade, and at the same time new objects are dimly appearing in mixture with the others. These others have soon vanished entirely, and the new scene becomes clear and perfectly defined. The mechanism by which these appearances are produced includes two magic lanterns, concealed near the front of the gallery, and throwing their imagery upon a screen suspended over the stage. The departing scene is caused to become dim and to disappear by gradually diminishing the light of its lantern, while the approaching scene is made to grow into brightness and reality by increasing the light of the lantern on which it depends. A succession of such views may be continued at will, including marvels which travellers go far to visit, and even striking events which history records, as the eruptions of volcanoes, the effects of earthquakes, like that of Lisbon in 1755. An endless variety of very ingenious exhibitions of this kind have been made, under the names of the *phantasmagoria,* or *raising of spectres, fairy dreams,* &c.

"*The* EYE *itself is, in fact, but a small camera obscura.*" (Read the Analysis, page 497.)

1057. Who could at first believe that the account above given of the camera obscura describes closely also that most interesting object in creation, the living eye itself;—the great inlet of man's knowledge, and the window through which is perceived much of what passes in the mind within! Yet the eye is really but a small camera obscura, combining all the parts above described as essential to the camera, and many more; but in that smallness still so perfect, that persons who delight in meeting around them the clear evidences of the power, wisdom, and goodness which willed this world into existence, point to the eye as one of the most striking and convincing of all. We shall now describe the eye and its actions; and keeping present the idea of the camera obscura, we shall find that the nature and uses of the various parts of the eye are declared by merely naming them. This paragraph should be perused while the reader can observe his own eye reflected in a mirror, or the eyes of friends near him.

1058. The *human eye* then is a globular chamber of the size of a large walnut, having for its outer wall C a very tough membrane, called, from its hardness, the *sclerotic coat;* in the front of this there is one round opening or window E B, named, because of its horny texture, the *cornea.* The chamber is lined with a finer membrane or web, the *choroid* (having relation to colour), which to insure the internal darkness of the place, is covered with a black paint, the *pigmentum nigrum.* This lining is bordered at the edge of the round window by what may be called a folded drapery, the *ciliary processes,* hidden from without by being behind the curious contractile window-curtain the *iris* (so named from its rainbow variety of colour in different persons), through the central opening of which, called the *pupil,* the light enters. Immediately behind the pupil is suspended by attachments among the ciliary processes, the *crystalline lens* D, a double convex perfectly transparent body of considerable hardness, which so refracts the light passing through it from external objects, as to form perfect images of these objects, in the way already described, on the back wall of the eye G, over which the optic nerve, there called the *retina,* is spread as a second lining. The eye is maintained in its globular form by a watery liquid, which distends its external coverings, and which in the space before the lens, or *the anterior chamber of the eye,* being perfectly limpid, is called the *aqueous humour,* and in the remainder or larger *posterior chamber,* being inclosed in a pellucid spongy structure, so as to acquire somewhat of the appearance of melted glass, is called the *vitreous humour.*

The annexed figure represents an eye of the common dimensions, supposed to be cut through its middle, from above downwards, so as to show the edges of the coats, &c. C is the outer or *sclerotic* coat, known popularly, where most exposed in front



and covered with a whitish membrane, as the *white of the eye.* A is the transparent cornea joined to the edge of the round opening of the sclerotic: it is more bulging than the sclerotic, or forms a portion of a smaller sphere than the general eyeball, so that while it may be truly called a *bow-window,* it, with the convex surface of its contained water, forms a powerful lens for acting to converge the pencils of entering light. At B, and similarly all round the edge of the cornea, is attached the window-curtain or *iris,* shown here edgeways, immersed in the aqueous humour, and extending inwards from above and below towards its central opening or *pupil,* through which the rays of light are passing to the lens. The iris has in its structure two sets of fibres, the circular and the radiating, which cross and act in opposition to each other, keeping the membrane flat and tense:—when the circular fibres contract, the pupil is lessened, when the radiating contract, it is enlarged; and the changes happen according to the intensity of light and the state of sensibility of the retina, as may at any time be proved by closing the eyelids for a moment to make the pupil dilate, and then opening them towards a strong light, to make it contract. Behind the pupil is seen the *lens* D with its circumference attached to the *ciliary processes* E: it is more convex behind than before. The disease of the eye called *cataract* (from a Greek word implying *obstruction*), exists when the lens becomes opaque, and the cure is to extract the lens entirely, or to depress it to the bottom of the eye, and then to substitute for it externally a powerful artificial lens or spectacle-glass. The three lines marking here the external wall or boundary of the eye stand for its three coats as they have been called, the strong *sclerotic*, and the double lining of the *choroid* and *retina*. The figure of a cross is represented upon the back part of the retina as formed by the light entering from the cross without (which cross has to appear here small and near, although representing one large and distant). The image of the cross is inverted, as explained for the camera obscura: but we learn that the perception of an object may be equally distinct in whatever position the image fall on the retina. It has been explained above, that a lens can form well imagery of great extent only on a concave surface,—and the retina is such a surface. The present diagram further explains what is meant by the *anterior* and *posterior chambers* of the eye, namely, the compartments which are before and behind the crystalline lens D.

1059. The nature of the eye as a camera obscura is strikingly exhibited by taking the eye of a recently-killed bullock, and after carefully cutting away the back part of the two outer coats, going with it to a dark place and directing the pupil towards any brightly illuminated objects. There may then be seen through the semi-transparent retina, left as a screen at the back of the eye, a minute but perfect picture of all the objects in front—a picture, therefore, formed on the back of the little apartment or camera obscura, by the agency of the convex cornea and lens in front, just as occurs in our artificial camera. The picture is inverted, for reasons explained above.

Understanding from all this, that when a man is said to be looking at an object, his mind is in truth only taking cognizance of the picture or impression made on his retina, it excites admiration to think of the exquisite delicacy of texture and of sensibility which the retina must possess, that there may be the perfect perception which really occurs of even the separate parts of the minute images there formed. A whole printed sheet of newspaper, for instance, may be portrayed on the retina on less space than the surface of a finger-nail, and yet not only shall every word and letter be separately perceivable, but, in the centre of the picture at least, even an imperfection of a single letter. Or, more wonderful still, when at night an eye is turned up to the wide vault of heaven, there is portrayed on the little concave of the retina the whole boundless concave of the sky.

1060. *Upright Vision from Inverted Images.*—Because the images formed on the retina are always inverted as respects the true position of the objects producing them—just as happens in a simple camera obscura,—persons have wondered that things should appear upright, or in their true situations. The explanation is simple. It is known that a man in bed with his cheek on the pillow judges as correctly of the position of the objects around him, as any other person—never deeming them to be inclined or crooked, because their images on his retina are inclined in relation to the natural perpendicular when the head is erect. And boys who at play bend themselves down to look backwards from between their knees, although a little puzzled at first, because the usual position of the images on the retina is reversed, soon see as correctly in that way as in any other. It appears, therefore, that while the mind studies the form, colour, &c., of external objects in their images as pictured on the retina, it judges of their position, not by the accidental position of the images on the retina, but by the direction as ascertained by the touch and experience, in which the light comes from the object and its parts towards the eye—no more deeming an object to be placed low because its image is low in the eye, than a man in a room into which a sunbeam enters by a hole in the window-shutter, deems the sun low because its image is on the floor. A candle carried past a key-hole, throws its light on the opposite wall, so as to cause the luminous spot there to move in a direction the opposite of that in which the candle is carried; but a child must be very young who has not learned to judge at once of the true motion of the candle by the contrary apparent motion of the image. A boatman, who, being accustomed to his oar, can direct its point against any object with great precision, has long ceased to deem it strange that when he desires to move the point of an oar in some one direction, his hand must move in the contrary direction. Now the seeing things upright, by images which are inverted, is a phenomenon akin to those here reviewed.

1061. *Single Vision with two Eyes.*—Another question somewhat allied to the last is, why, as we have two eyes, and an image of any object placed before them is formed in each—why the object does not appear to us to be double? In answer to this, we have again to state the simple facts of the case. As in two chess-boards there are corresponding squares, so in the two eyes there are corresponding points, and when on those points, or very near them, a similar impression is made at the same time, the sensation or vision is single and distinct; but if the impressions be made on points which do not correspond—

owing to some disturbance of the natural position of the eyes, the vision becomes double and indistinct. The sympathy of a pair of healthy eyes is so strong, that from earliest infancy they constantly move in perfect unison. By slightly pressing a finger on the ball of either eye, so as to prevent its following the motion of the other, there is immediately produced the double vision. Tumours about the eye may have the same effect. Persons who permanently squint have always double vision; but they acquire the power of attending to the sensation in one eye at a time. Animals which have the eyes placed on opposite sides of the head, so that the two can never be directed to the same point, must have in a more remarkable degree the faculty of thus attending to one eye at a time.

1062. The corresponding points in the two eyes are equidistant, and in similar directions to the right or left sides from the centres of the retinæ, which centres are called the points of distinct vision, and at them the imaginary lines named the axes of the eyes begin or terminate; but it has to be remarked that these points, in being both to the right or both to the left of the centres, must be one of them on the inside or between the centre and the nose, and the other on the outside, between the centre and the ear, from which fact arise important consequences. When the two eyes are directed to any object, or rather point of an object, their axes meet at it, and the centres of the two retinæ are exactly opposite to it, giving the sensation of single distinct vision; but the images formed at the same time, of objects nearer to or farther from the eye than the first supposed, cannot fall on *corresponding* points, for an object nearer than where the axes meet would have both its images on the outsides of the centres, and an object more distant would have both its images on the insides of the centres, and in either case the vision would be double. Thus if a person hold up one thumb before his eyes, and the other in the same direction, but farther off, by then looking pointedly and steadily at the nearer, the more distant will appear double, and by then looking similarly at the more distant, the nearer will appear double; and the same happens whatever other objects at different distances are viewed in the same manner. (See Art. 1118.)

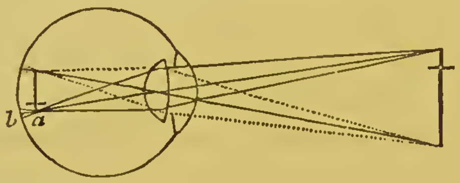
1063. The reason for applying the term "point of distinct vision" to the centre of the retina, is felt at once by looking at a printed page, and observing that only the two or three letters to which the axis of the eye is directed, are distinctly seen; and, consequently, that although the whole page is depicted on the retina at once, the eye, in reading, has to direct its centre successively to every part. Then it may be remarked, in viewing the diagram of the eye, that the centre of the retina is more distant from the lens than any other part of it, and, consequently, that when the centre is at the true focal distance required for the formation of a perfect image, no other point of the retina can be so at the same time.

1064. On examining a dead eye, the point of distinct vision is distinguishable from the retina around by being rather more transparent. It might have been expected that this point would be where the optic nerve enters the eye: but, in fact, the optic nerve enters, considerably nearer to the nose than the point of distinct vision; and the part is altogether blind or insensible. Had the two optic nerves therefore entered at points of the retina *corresponding* (in the sense explained above), there would have been an invisible spot on every object, opposite to the insensible points; but as the case really stands, the part of any object from which the light passes to the insensible or blind part of one eye cannot be opposite to the insensible part of the other. The existence of the blind spot, where the nerve of the eye enters, is discoverable by placing in a row on a table some small objects, as coins or wafers, about three inches apart, and, one eye being closed, by looking with the other at a middle object of the row: the object next to that, on the outside, will then be invisible, although those still farther off will remain in sight. Another mode of proof is to shut one eye while looking with the other at the nails of the two thumbs held together before the face; on then moving the outside thumb sideways away from the other, while the eye continues directed to the other, the moved one, when at the distance of about three inches, will disappear, but will come into view again when still farther removed.

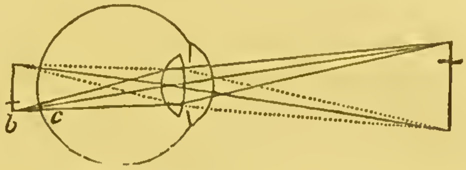
1065. It appearing, from the explanations now given, that there cannot be perfect sight unless where a perfect image is formed on the retina; and the truth having been formerly explained, that perfect images behind any lens will be formed at different distances from it, according to the various distances of the objects in front, that is to say, according as the pencils of light which fall upon it have more or less of divergence in them, it follows, that the eye in being able, as it is, to see distinctly objects at different distances (the shortest is about five inches), possesses a power of altering the relation of its parts to accommodate itself to the circumstances. We do not yet accurately know whether it does this by lengthening or changing the form of the ball through the action of the surrounding muscles, or by changing the place or the form of the lens.

Among the eyes of the myriads of mankind, however, it happens that all do not originally possess such powers exactly in the requisite degree, and that many lose them from a natural decay as life advances.

Persons are called *short-sighted* whose eyes from too great convexity of the cornea or lens, have so strong a bending or converging power that the rays of light entering them are brought to a focus before reaching the retina—at *a*, for instance, instead of at *b*; so that the rays, when spreading again beyond the focus, where they cross one another, produce on the retina that sort of indistinct image which is seen in a camera obscura, of which the screen is too distant from the lens. This defect of sight obliges the individual, when using the naked eye, to hold objects very near to it, that the consequent greater divergence of the rays may be proportioned to the unusual refracting power of the eye;—or the person may find a remedy in placing concave lenses between the object and the eyes, which lenses, by lessening the convergence of the rays from objects at a usual distance (as explained at Art. 1036), cause the perfect images in the eye to be formed farther from the lens, and thereby on the retina itself. Without *concave spectacles*—as the lenses are called when fixed together in a frame—persons with the defect now under consideration cannot see objects distinctly from a distance exceeding ten or twelve feet. This defect often diminishes with years, so that the person who in youth needed strong spectacles, in old age sees well without them.



1067. There is the opposite defect of deficient convergent power in the eye, dependent on a too great flatness of the cornea or lens, and which is much more common than the last-mentioned defect. The great majority of persons after middle age begin to experience a degree of this. In such cases the rays of light are not collected quite into a focus when they reach the retina; they would meet only at *b*, for instance, instead of, as they should do, at *c*, and hence the image is indistinct, in the same manner as in a camera obscura, when the screen is held too near to the lens. Persons suffering this defect cannot, when using the naked eye, see distinctly any object very near to it, because the deficient converging power of the eye cannot conquer the great divergence of rays coming from a near point; hence, they will remove objects under examination, as a book or newspaper, to a considerable distance, even to that of arm's length, so as to receive from them only rays nearly parallel. These persons, in contradistinction to the last described, are called *long-sighted* persons. This defect is remedied by the common convex spectacles, which do part of the converging work, so to express ourselves, before the light enters the eye, leaving undone only that which the weakly converging eye can easily accomplish. As this defect, like the last, is met with in all degrees, spectacles must be chosen accordingly. Certain curvatures or strengths of these have been particularized and numbered as naturally belonging to different ages or periods of life, but each person should choose under the direction of a competent judge, until that strength be found which enables him or her to read, without any straining of the eye, at the common distance of about twelve inches. We cannot reflect on this part of our subject without admiration at what science has accomplished in assisting and restoring human sight, after the organs, from age, have become enfeebled. Now that in civilized society, the common employments and enjoyments of life require a visual power capable of distinguishing such minute objects as written and printed characters, to deprive old people of their spectacles, would be to condemn many of them to a kind of painful inactivity for the remainder of their lives.



1068. Up to a recent time it was believed that the change in the state of the eyes, which comes on about middle age, obliging most persons to use spectacles, was simply a weakening of the converging power of the eyes; but the writer found, in his own case, that the defect arose chiefly from double images of the objects being formed in each eye, one image being strong, as usual, and the other being more faint, overlapping the first, and jutting beyond it towards the right hand. For a time he deemed this a peculiarity in his own case, but accident leading him to examine further, he found that a great majority of the persons using spectacles had the same defect. As the age of these was greater, the double vision was more marked, and the displacement to the right of the fainter image was greater. Old people found that while a broad object had only a shadowy projecting edge on the right side, tall narrow objects, like a flag-staff, a long chimney, or a slender steeple, appeared two, standing distinctly apart. The parties had not been clearly aware of the fact, but it was easily proved thus: Two lines of equal strength or breadth are drawn on paper directly crossing each other. If such cross be then held before the eyes, one line being vertical and the other horizontal, the horizontal line appears thicker and darker than the other. The explanation is, that the displacement to one side (generally the right side) of the faint image of the cross leaves the horizontal lines of both still coinciding, and therefore dark, while the vertical lines are separated, and therefore appear broader and less dark. To a person having this defect, a printed page seems to have double letters, and if the lateral displacement amounts to only half the breadth of a common letter, the faint downward lines of the one set appear between the stronger lines of the other, and darken all; but if the displacement be greater, the shadowy lines may coincide with the stronger, and so are, in great part, concealed, except at the very end of the lines. The same clearing effect may be produced by holding the page farther from the eyes. Happily the common spectacle lenses remedy, to a considerable extent, this defect, as well as the feeble convergence.

1069. An eye much accustomed to examine near and minute objects, may lose something of its pliancy, and become defective when tried at distant things, as that of the miniature painter, the engraver, &c. On the other hand, the old seaman's eye, which has so often and uninterruptedly been directed to the distant horizon, straining to catch the view of an expected sail, or of land, has a power of judging of distant things which surprises, while in regard to small, near things, it experiences deficiency.

1070. A man who tries to see with the eyes under water has very indistinct vision, because the difference of density between water and the eye not being so great as between air and the eye, the bending or refraction of light entering from the water is not so great as to produce perfect images on the retina. Aid would be given in such a case by using very convex spectacles. It is to meet the necessity of the case that the lens of a fish's-eye is extremely convex, or almost a ball. The white round ball found in the eye-socket of a boiled fish is the crystalline lens of the fish coagulated or hardened, as white of egg is hardened during the boiling.

There are important considerations connected with the sensibility of the retina, which regard rather the laws of life than of light, but which require attention here.

1071. Any impression of light made upon the retina lasts for about the sixth part of a second. Hence when the burning end of a stick is made to sweep rapidly across the view, its path appears to the eye to be a long continuous line of light; and if it be made to revolve in a circle six times in a second, as when moved by the hand, or fixed to a turning wheel, that circle will appear to the eye to be a complete ring of fire. A small polished ball of steel on the end of an elastic wire, of which the other end is fixed in a block of wood, when caused to vibrate, similarly forms a line or a curve of light. A harp-string while vibrating as it sounds, appears like a flat transparent riband. Lightning or other meteor darting across the sky, although in fact but a single luminous point, is generally thought of as a line of light: the term forked lightning has reference to this illusion. The same remark applies in a degree to a sky-rocket in its rapid ascent. Two or more colours painted separately on the rim of a wheel which is made to turn rapidly, appear to a spectator to be these colours really mixed:—it has been explained already how patches of all the colours of the rainbow, when mixed in this way on a turning wheel, form white light. If on one side of a card a little bird be painted, and on a corresponding part of the other side a cage be shown, on then making the card turn rapidly by twisting between the fingers and thumbs threads fixed to its opposite edges, the bird and cage will be seen at once, and the bird will appear to be within the cage. Dr. Paris displayed taste and amiable ingenuity in designing this toy with great variety of subjects.

1072. A certain intensity of light is necessary for distinct vision, but the degree varies much according to the previous state of the organ. A person passing from the bright day into a shaded room, may for a time fancy himself in almost total darkness, but by persons sitting in the room, and become accustomed to the feeble light, every object is clearly seen. The dawn of morning after the darkness of night appears much brighter than an equal degree of light in the evening. When, as the night falls, lamps or candles are first introduced, their moderate glare is often for a time offensive to the eye; and a similar feeling, but still stronger, is experienced, when in the morning, bedroom window-shutters or close-drawn curtains are suddenly opened. After the repose of night, the sensibility of the eye, when first opened, is often such that the globules of blood moving in the capillary vessels of the retina produce the impression there of little balls of light pursuing one another along the tortuous vessels. To a prisoner after long confinement in a dark dungeon, the full light of day is almost insupportable. A dungeon, which to unaccustomed eyes is utterly dark, still to its long-held inmate may seem feebly illumined. There are instances in the records of the barbarous ages, of prisoners confined for years in darkness, deemed absolute, but where, after a time, they had made entertaining companions of the mice and spiders in their cells. The darkness of a total eclipse after bright sunshine appears deeper than it really is. The long polar night, which lasts for months, ceases to appear very dark to the inhabitants of the country.

If an eye be directed for a time to a black wafer laid on a sheet of white paper, and be then turned to another part of the sheet, a portion of the paper at that other part, of the size of the wafer, will appear brilliantly illuminated; because the ordinary degree of light from it appears intense to the part of the retina lately receiving almost none. An eye directed long and intensely to any minute object—as when a sailor watches a speck seen in the distant horizon, supposed to be a ship, or when a sportsman on brown heath keeps his eye fixed on a bird nearly of the colour of the heath, or when an astronomer gazes long at a little star—has the sensibility of its centre at last weakened, and ceases to perceive the object; but if the axis of the eye be then turned a little to one side of the object, so that an image may be formed only *near* the centre, the object may be again perceived, and the centre, in the meantime enjoying repose, will recover its power.

1073. But the most striking fact connected with the sensibility of the retina is, that if part of it be strongly exercised for a time, by looking at some bright-coloured object; on the eye being then turned away or altogether shut, an impression or spectrum will remain of the same form as the object lately contemplated, but of a different colour, deemed the opposite of the other. Thus if an eye be directed for a time to a red wafer laid on white paper, and be then shut or turned to another part of the paper, a beautifully-bright green wafer will be seen; and *vice versâ*, a green wafer will produce a red spectrum, and a cluster of wafers will produce a similar cluster of opposite colours. Then if the hand be held over the closed eyelids to prevent almost entirely the access of light to them, the spectrum of a bright object, lately viewed, will appear luminous surrounded by a dark ground, and when the hand is again removed the contrary will be true. Again, if the eye be considerably fatigued by looking at the setting sun, or even at a window with a bright sky beyond it, or at any very bright object, on then shutting it, the lately contemplated forms will be perceived, first of one vivid colour, and then of another, until perhaps all the primary colours have passed in review. These extraordinary facts prove that the sensations of light and colour, although excitable by light, are also producible without it. This truth gave occasion to Darwin's theory, that the sensation of any particular colour, as red, for instance, is dependent upon a certain state of contraction of minute fibres in the retina,—and that the fibres, when fatigued in that condition, seek relief when at liberty, by throwing themselves into an opposite state,—as a man whose back is fatigued by bending forward, relieves himself not by merely standing erect, but by bending the spine backwards. It is noticeable that the colours which thus appear opposites to each other in kind, are those nearly which when the solar spectrum produced by a prism, as described a few pages back, is painted round a wheel, are opposite to each other in place.

1074. There are persons who, although having distinct perceptions of form and of light and shade, have not the power of clearly distinguishing colours. It is common for such persons, of whom Dalton, the eminent chemist, was one, to deem red and green, which are naturally opposites, the same colour, and therefore not to distinguish difference of colour in a red berry and the leaves around it.

> "*The mind judges of external objects by the relative size, brightness, colour, &c., of the minute but perfect images or pictures of them formed at the back of the eye on the expansion of nerve called the retina; and the art of the painter is successful in proportion as it produces on a larger scale such a picture, which when afterwards held before the eye to reproduce itself in miniature upon the retina, may excite nearly the same impression as the original object.*" (Read the Analysis, page 497.)

1075. We now understand how an exact miniature resemblance of the objects before us is produced upon the retina of the eye, by the light from them refracted in passing through the different parts of the eye; but after all, this is only a picture, and the inquiry remains—which many persons would suppose so simple as to be trivial, but which is in reality very curious and important—how are we thereby enabled to judge of the magnitudes, distances, and other particulars respecting the things examined. Here it will be found, to the surprise of persons first entering upon the study, that we learn the meaning of a scene or of pictorial signs only gradually, as we do of any other system of signs, and that a person whose eyes, although perfect, had been kept covered from infancy up to maturity, would no more "see" and understand any scene on which he first opened his eyes, and so had a perfect picture of it on his retina, than a child understands or can read a printed page, when he first looks into a book. Highly interesting information has been obtained on this subject, by observing the facts where an obstruction from birth has, by surgical operation, been suddenly removed in persons arrived at maturity.

If a man were placed from infancy in an apartment fitted up as a camera obscura, and had no means of becoming acquainted with the external world, but by watching the images appearing from time to time upon the screen, he could learn scarcely anything of objects around him; but if after a time he were allowed to walk out, and to examine by the touch and by measurement the different objects whose images he had been in the habit of viewing, and to ascertain what size, shape, and distance of an object corresponded with a certain magnitude, form, position, and brightness of image, the transient imagery might at last be to him a tolerably clear indication of the real particulars;

making him in imagination present to the objects, nearly as if he went out and examined them with his hands. Thus, in a degree, the mind may be considered as stationed in or near the little camera obscura of the eye, from whence it cannot itself escape to examine external nature, but must learn the meaning of the images formed on the retina, through the services of the bodily members, and the other organs of sense, examining the realities. The judging of things by sight, then, is merely the interpreting one set of signs, as judging by sounds or language is interpreting another, and judging by hieroglyphics or any written characters is interpreting a third. The common visual signs on the retina, however, are among signs the most easily learned or understood, from having certain fixed relations in form, magnitude, and position to the things signified: while words, hieroglyphics, and written characters are quite arbitrary, and have no such relations.

Pictorial Representation and Perspective.

1076. Bodies, as visible objects, differ and are distinguished among themselves chiefly by their comparative dimensions, that is, their form and magnitude, or shape and size; and to ascertain these and the relative distances and positions, are the great objects which, by means of the eyes, the mind seeks to accomplish. It effects its ends by considering collectively.

1st. *The space and place* occupied by objects in the field of view, measured by what is called the *visual angle.*

2nd. *The intensity of light, shade, and colour.*

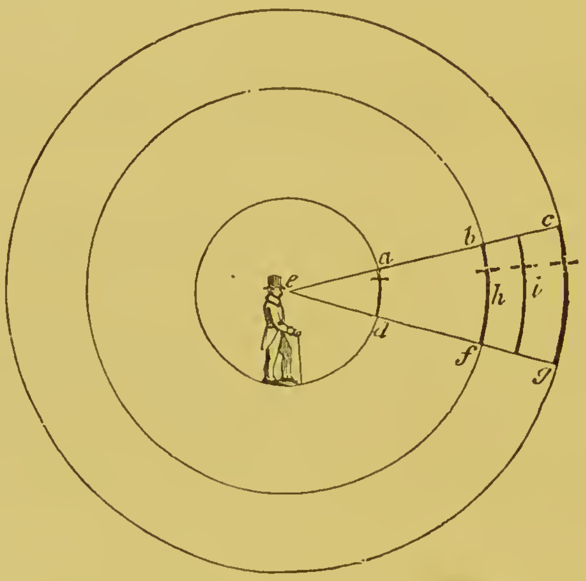
3rd. *The divergence of the rays of light entering the eye.*

4th. *The convergence of the axes of the eyes viewing an object.*

We shall treat of these particulars separately in the order now stated. It will facilitate the understanding of this part to read first the sketch of popular mathematics in the Appendix of the volume.

1st. *The space and place occupied in the field of view, measured by the visual angle.*

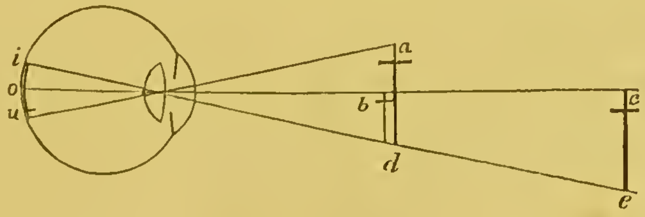
1077. The term *field of view* is used to designate that open or visible space before the eyes, in which objects are seen; and it may mean either the smaller field visible in one position of the person's head, or that which is commanded on directing them all round, and is called *sphere* of vision. If a man, as at *e*, were surrounded by a globe or sphere of glass as *a*, through which his eye placed at the centre might view the several objects around occupying certain situations and certain proportions of the circumference; and if the globe had any equal divisions or degrees marked upon it all around, like the lines marking, on a library globe, the degrees of longitude and latitude, he would be able at once to say exactly what portion of his sphere or field of view was shadowed or occupied by any single object, as the cross here shown at *i*, and thus to describe very intelligibly, either for his own recollection, or to inform others, its relative magnitude and situation as then appearing to him. For example, he might say, on looking at a tree in the garden through a common window (which is a portion of the field of view really divided by the cross bars), whether he saw the whole tree through one pane or through several, and through which pane or panes he saw it. It may be remarked farther, that whether the supposed sphere of glass were large or small, *viz.*, were as indicated at *a*, or *b*, or *c*, the part of its surface apparently occupied by any object either beyond it or within it, would bear the same proportion to the whole surface; —if *a d* were a tenth of the small circle or globe, *c g* would be a tenth of a larger. Now as it has been found convenient to consider a circle (and every circle) as divisible into 360 parts, to be called degrees (which are smaller therefore in a small circle than in a large circle, although in each having the same relation to the whole), the ready mode of comparing the apparent magnitude



of objects is to say how many of these degrees of the field of view, in length or breadth, each object occupies: and this is what is meant by the apparent size of an object. Then because the most convenient way of measuring a portion of a circle, of which the whole is not seen, is to measure by a fit instrument the angle or corner formed at its centre by lines drawn from the extremities of the portion to the centre,—as here the angle at *e* formed by the lines *c e* and *g e*, the object is said either to occupy a certain number of degrees of the circumference of the circle, or to subtend an angle of the same number of degrees at its centre, and this angle is called the *visual angle*, the subject of our present observations.

1078. It is important to advert here to the difference between the length of line which measures the height or breadth of an object, and the amount of surface or space occupied by it in the field of view, the latter being always as the square of the former (see Art. 26). A single pane of glass one foot high and one foot broad forms a small window, but a window two feet high and broad has four such panes, and a window of ten feet borders has 100 such. The full moon in the sky has breadth, or visual angle of nearly half a degree of the celestial vault; a moon twice as broad would have four times the surface. In the adjoining diagram of the field of view, the figures of the cross span about 30 degrees of the circles, and the cross itself is made curved to coincide with the circle; but for small angles the portions of the circle included between the bounding lines being so short are regarded as straight lines without leading to error. The adjoining figure illustrates several of the matters here referred to.

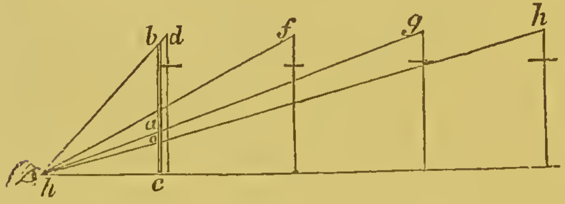
1079. The visual angle, in regard to any object, being that included between the two lines or rays, as *a u* and *d i*, which pass from the extreme points of the object, *a d*, for instance, to form the extremes of the corresponding image on the retina at *i u*; it is



evident, as shown also in Art. 1049, that the same angle is formed by the rays on each side of the lens, and that the image on the retina is less than the external object in exact proportion as its distance from the centre of the lens is less than that of the object. It follows also, therefore, that the small cross *b d* produces the same sized image on the retina as the cross *c e*, which is twice as large, but twice as distant; and that an image only half as large as that from the cross *a d*, when near, is produced by a similar cross *c e* when twice as far removed. The visual angle then becomes an exact indication of the size of the object when the distance is known, or of the distance when the size is known.

Many familiar facts receive their explanation from the law of the visual angle or apparent size being less always in proportion as the distance of an object is greater.

1080. A man (or the cross here substituted for simplicity) at *d*, standing near the outside of a window, *b c* (here supposed to be seen edgeways), may to the eye of a spectator within the window at *h*, subtend the same visual angle, or appear as tall as the window, the light from the man's head passing through the top of the window, and that from his feet passing through the bottom: but if the man then move away from the window, the eye of the spectator will be able to see his whole body through a smaller and a smaller extent of the window, as his distance increases; through half its height or *a c*, when he is twice as distant, or at *f*, and through the third or *o c*, when he shall be three times as distant, or at *g*, and so forth, for any other distance; so that soon a small figure of a man cut in paper, if applied upon the glass, would exactly cover the part of it through which the light from his body entered to the spectator's eye, and would then, by completely hiding him from view, be an exact measure of his *apparent* size: at last a fly passing over the pane might equally hide him, and the fly then would subtend a larger visual angle than he does, that is, would be forming on the retina a larger image than the man. Thus it may happen, that a person sitting near a window, and intent upon some subject of study or of conversation, may for an instant mistake a fly on the glass for a man at a distance; or, on the contrary, a man for a fly.



1081. In accordance with the principle now explained, a telescope has been constructed, in which the field of view is divided by fine cross wires, or otherwise, so that the person using it can say at once how much of its field any object occupies. When ships are in chase, it is common by such an instrument, which will detect a change of visual angle, or apparent size, to view the fleeing or pursuing ship; and if the apparent size be observed to increase, the conclusion follows that the ships are nearing each other; if, on the contrary, the size diminishes, the chased ship is escaping.

1082. By computation according to this rule, whenever the real size of a distant object is known, the distance is ascertainable, and, *vice versâ,* when the distance is known the size is determinable:—for it is evident that if a body, as a ship, known to be 100 feet tall, occupy or subtend in the field of vision the 360th part of a whole circle, or one degree, the whole circle must be in circumference 360 times 100 feet, or 36,000; and the diameter of any circle being $\frac{1}{3}$, or more nearly $\frac{7}{22}$ of its circumference, while in the case supposed the distance of the ship is the half-diameter, we learn that distance. Again, if we know the distance of a ship or other object to be a mile, and if we then find the visual angle subtended by the object to be the 1,000th part of a circle, we know its true size to be the 1,000th part of a circle, of which the half diameter or radius is one mile. It is by applying this rule in a manner to be afterwards explained, that the size of the heavenly bodies is determined.

1083. Few persons are aware of how rapidly the apparent magnitude of an object diminishes on its being removed farther from the eye. A remove of a hundred feet renders the image formed on the retina by any object nearly 100 times smaller than when the distance is one foot. Now, in the unaided human eye, the power of seeing minute objects has a limit, namely, when the object subtends in the field of view, an angle of space of less than half a minute. (See the Mathematical Appendix). There are many kinds of minute animals thus hidden from common unaided vision, owing to their small size, but which the microscope clearly shows, and proves them by their activities, to see one another as larger animals do. It has been common to believe that mere distance prevents the eyes from seeing minute things somewhat as a fog or other such obstacle does, and not because of the small size of the images then formed on the retina.

1084. We now perceive that if the rays of light coming to the eye through a plate of glass set in a picture-frame, from objects seen beyond it, could leave marks in the glass at the points where they pass, and marks capable of giving out the same kind of light as the objects give, there would be formed *upon* the glass such a representation or picture of the objects viewed *through* it, that when held before the eye, it would produce on the retina an image or images the same in almost all respects as the objects themselves. From the different points of the glass, light would shoot to the eye of the same kinds and in the very same directions as that originally coming from the objects. Now the art of painting seeks so to dispose lights, shades, and colours on some plane surface, as to produce the sort of representation of objects here contemplated, while the picture-frame stands in lieu of the window-frame, or border of any opening through which the true scene is supposed to be viewed. It is admirable how perfectly this art now accomplishes its ends; and although there are still differences between the effect upon the eye, of a picture, and of the realities,—which differences we shall consider presently, and how they may be combated so as to render the illusion almost perfect,—it is not one of them, as might be supposed from the small extent of the canvas, or plane of the picture, that the images made on the retina are smaller than when produced by the objects themselves. Few people, before studying this subject, are aware that in good pictures the different figures are in size made such, that at the distance from the eye at which the picture is meant to be viewed, they produce on the retina the very same size of image as would be produced by the realities seen under the aspect represented in the picture. To become sensible of this, a person may look through a window-pane, having the eye fixed, at the distance of a foot from it, and may trace with a sharp point or pencil upon the glass (previously coated with gum), the outline of the scene beyond, perhaps a street or garden—and he will find, that the outline of a man seen there at the distance of thirty paces, made perfectly to coincide with the person, so that, if opaque, it would just hide the person, will be scarcely half an inch tall, while the figure of a man a few hundred paces off will be so small that the eyes, nose, and other features, could not be distinguished, even if they could be drawn.

1085. It is remarkable that, although no fact in nature is more familiarly known to all, than that the apparent size of bodies is constantly changing to a person moving about among them, as explained in the preceding paragraphs, few have stated to themselves that philosophical truth. They soon learn, even as children, to make the necessary allowances, and move about safely among the things around them, judging correctly enough of sizes and positions of things. Then, as a person who reads the description of an elephant, does not deem the animal larger or smaller because of the size of the types used in the printing, or of the accompanying engraved representation; and as a man, in a picture-gallery, viewing miniatures and larger portraits, does not conceive of the originals according to the size of the representations; and as a man viewing a correctly-executed picture of a Grecian temple, never dreams, unless his attention be specially directed to the fact, that upon the canvas, the distant pillars of the rows are drawn much shorter than the near ones—the mind in all such cases merely using the *signs* to help it to conceive of the *things* according to previous knowledge, or to other principles of judging;—so in any common case of examining by the eyes, the mind takes small account of the *apparent* size of objects, but passes instantly from the types to the realities, already in general more or less known. Few persons, for instance, reflect on the fact, that when two friends shake hands, each appears to the mere eye of the other much taller than when either has gone some paces away; or that one chair of a set, at the end of a room appears to a person sitting at the other, only half as large as a chair in the middle of the room. But such facts may be immediately proved by looking through a tube or a ring at the same object when placed at different distances from the eye. Of a chair standing near, only a small part will be visible through the tube, while of a distant chair, the whole and others around may be seen. At a few miles distance, a fleet of a hundred ships, or a mountain, may be seen through a finger ring as the picture-frame. There are occasions, however, where previous knowledge and common collateral helps to the recognition of objects being wanting, the observer's attention is strongly aroused to the fact of the diminutive appearance produced by their distance:—for instance, when a man, after a long sea voyage, first approaches a land, of which the features are new to him, as when a European first arrives on an Indian coast, he can scarcely believe that the little specks which he sees scattered along the shore are spacious dwellings, or that what seem to him only luxuriant herbs or bushes, are magnificent palm-trees.

1086. For the same reason that a distant body to the naked eye appears diminutive, namely, the smallness of the visual angle subtended by it, so does a distant motion to the eye appear slow. A railway train dashing past a spectator at rest, may startle, nay, appal him by its speed; but if viewed, at the same time, by another from the side of a distant hill, it seems to be gliding gently along. A ship driven before a tempest, seems to a sailor on board almost to fly through the white foam which surrounds her; but if then seen by a spectator on shore, she is scarcely perceived to change her place. A balloon high in the air, borne along on the wings of the wind, at the rate of seventy or eighty miles an hour, may still for a considerable time leave a spectator on earth doubtful as to whether it be in motion at all, or in what direction it moves. The moon in her orbit wheels round the earth at the rate of hundreds of miles an hour, yet, owing to her distance from it, her motion is not visible to the naked eye of the inhabitants of the earth, except by comparing her positions at considerable intervals of time. In respect to bodies still more distant than the moon, the truth at present under consideration is still more striking.

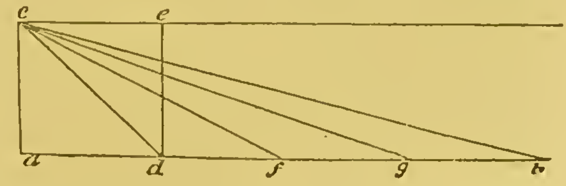
Having now explained how the apparent transverse measure or breadth of bodies and of space, in other words, the visual angle subtended by them, is affected by their distance from the eye, we proceed to show how it is affected also by their position.

1087. Because light moves in straight lines, no part of an opaque body can be seen, between which and the eye there is not straight open space. A globe before the eye, however turned, preserves the same appearance in the field of view, and its outline traced upon a plate of glass held across between it and the eye, is, like its direct shadow upon a wall, always a circle; but an egg, which if held in one position produces a circular outline or image, when held in another, produces an image which is oval. A wheel when viewed sideways appears a perfect circle, when viewed edgeways it appears a broad straight band or line, and in any intermediate position it appears oval. The *apparent* form of a body then may give only partial information as to its shape, to be taken with the experience of seeing it in other aspects. If a man had never seen an egg but endways, he could not have known that it was not a sphere.

If any long straight object, as a wooden beam, be placed with one of its ends directly to the eye, that end only can be seen, and according to the case may appear a square or circle of the diameter of the beam; if it then be placed with its side directly to the eye, its whole length will be seen; and if placed in any intermediate position, it will appear more or less shortened;—in all cases, its outline on the retina being similar to that of its shadow on a wall behind the person. A man has advanced on the point of a spear turned directly to his eye without seeing it, or on the end of a bar of iron carried on the shoulder of a porter in the street. A common telescope held with its end to the eye appears a perfect circle, if then inclined a little, it seems to jut out on one side, and as the inclination is increased, it juts out more and more, until it displays its whole length. A great ship of war, of which the stern is towards a near spectator, might appear to him a round wooden building with ordinary windows; but as it turns, or as the spectator moves to one side, it gradually reveals the long batteries of cannon. A straight row of a thousand similar objects, as of trees, pillars, soldiers in rank, &c., may appear to a person at the extremity as only one object of the kind, the nearest individual completely hiding all the others; but if viewed from the side and at a certain distance, the individuals may be counted.

The appearances now treated of exemplify what is called *foreshortening*, and are to be noted wherever surfaces or lines are not placed so as directly to face the spectator.

1088. One of the commonest cases of foreshortening is when the eye looks more or less obliquely along an extended plane surface, on the ground, for instance, or on the face of the sea, by estimating aright the foreshortening of which, judgment is formed of the distance or situation of the objects placed thereon. And it will be readily perceived that in all such cases the more distant portions of the surface are progressively more foreshortened than the nearer. Thus, a man standing at *a* on a plain as *a b*, with his eye at *c*, if looking down before him, looks on a portion of the surface *a d* almost directly, or with little foreshortening, and an extent, as *a d*, equal to the height of the eye, will subtend in his eye an angle of 45°, or half a right angle, *viz.*, the angle *a c d*, which is half of the whole angular space subtended from his feet to



the horizon, however distant; the next equal portion of the plane, *viz.*, *d f*, will subtend a much smaller angle, *viz.*, *d c f*, the next, *viz.*, *f c g*, an angle smaller still, and so on, as he carries his view more and more forward, the surface becoming more and more oblique to his visual ray, until at last the light rather skims along the level than rises. This explains why a person having a side view of a row of separate objects, as of men in line, trees, pillars, &c., can look through or between the nearest of them, but towards the extremity sees them as if standing in close contact, or as if forming a continued surface. The same remark explains why distinct masses of cloud, scattered uniformly over the sky, with wide intervals of clear blue between them, may appear to a spectator, anywhere on the ground, to form, towards the distant horizon, a dense unbroken bed.

1089. If a man standing on a hill look down upon a field or plain which is known to him, and if he see some objects near its side, and some near its middle, and some near its distant border, he judges fairly by the angles how far they are from him and from one another. Similarly, when viewing the ocean from a lofty peak, and seeing ships scattered over its face, he judges tolerably of their distance, for he can see only a certain extent of ocean which becomes to him as a known field. The man stationed at the flag-staff on the High Knowl of the island of St. Helena, looks down upon a circular field of the Atlantic a hundred miles broad, and can tell the distance of any sail in sight, to within a few miles. Although the ground plan of an extensive landscape may not be so level as the face of the ocean, there is still an approximation, which considerably assists a spectator's judgment of dimensions.

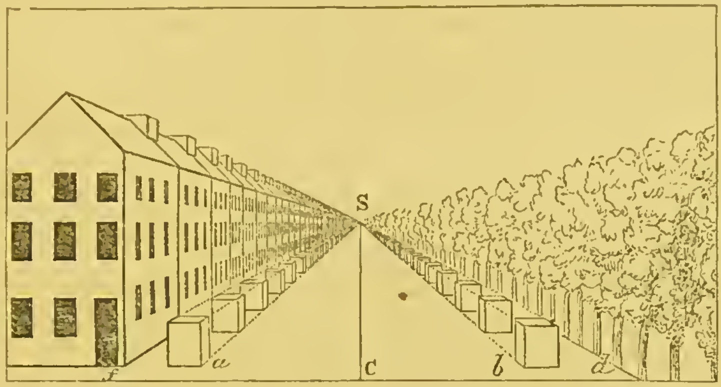
1090. Painters are careful not only to foreshorten, according to the proportions explained above, all the objects seen obliquely which they portray, but they avail themselves of the principle to produce very striking effects. For instance, the accomplished Martin, the painter of *Belshazzar's Feast*, in many of his beautiful designs, by judicious foreshortening, exhibited miles in extent of gorgeous architecture and of armed men, on a very small extent of canvas: he made a single magnificent pillar or accoutred warrior in the foreground, serve as the type which first warmed the mind with admiration, and then sent the conception along retiring lines of beautiful perspective, where every tip or edge renewed the first impression. A man lying on a high table or bed, with his feet towards the spectator, is foreshortened into a roundish heap, of which the soles of the feet hide the greater part. This is the description of the painting which was called the "Miraculous Entombment," in viewing which an unreflecting spectator, while moving sideways, with the expectation of seeing more of the body, still saw only the soles of the feet, and could suppose the body to be turning round so as to keep the feet towards him. For nearly the same reason, the eyes of a common full-face portrait may seem to follow a spectator while going to different parts of the room,—for by moving to a side of the picture he cannot see the side of the eye-balls. It is related of a murderer, that he was impelled at last to commit suicide by observing that the eyes of the portrait of his victim were always fixed upon him. A rifleman portrayed as if taking aim directly in front of the picture, appears to every spectator to be pointing at him specially.

1091. As the painter, availing himself of a knowledge of the principles now explained, by which the eye usually judges of size and distance, may produce on his canvas charming illusions, so may the tasteful proprietor of ornamental gardens and pleasure-grounds, by working his solid levels into artificial undulation of hill and dale, and clothing these with tree and edifice of magnitudes to correspond—make the eye of a spectator contemplate supposed extensive plains, lofty mountains, spacious lakes, and distant pagodas—all within the narrow space of a few acres; so, by another set of means, producing on the eyes of observers nearly the same impressions as Claude, Poussin, or Turner, have given by their noble pictures.

1092. When the representation of any object or mass of objects is foreshortened, because one part has to appear farther from the eye than another, that part is made in a proportion smaller than equal parts nearer. For example, in a straight row of similar houses, pillars, trees, &c. (see the next cut), those nearest to the eye will, on a pane held before the eye to receive their light, occupy the larger space, and there will be a gradual diminution from the largest to the least, so that lines drawn upon the glass along the tops and bottoms of the images would tend to a point, called, for a reason to be explained below, the *vanishing point*. Thus a person looking from a window along a straight street, must, to see the chimneys of the nearest house, look through the top of the window, and to see the street-door must look through the bottom; but the most distant house, both top and bottom, is to be seen through a small extent of the glass level with the height of the eye. This remarkable tapering of foreshortened objects may of course be strikingly observed on looking at any correctly-made drawing or engraving meant to represent a retiring row of similar objects;—such drawing being, in truth, an attempt to realize by art, on the surface of a sheet of paper, the appearance of the objects as seen through a window or aperture of the size of the paper; or, as would be seen on the glass of a window if rays of light could leave marks in passing.

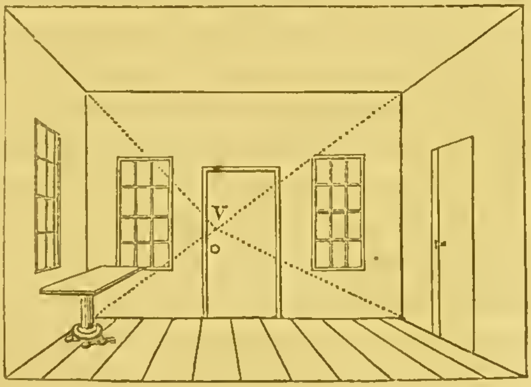
The art which gives rules for tracing objects on a plane surface, as they would appear to an eye looking at them through that surface if transparent, with their various degrees, first, of apparent diminution, on account of distance, and, secondly, of foreshortening, on account of the obliquity of view, is called, from the Latin word signifying *to look through,* the *art of perspective.* It regards chiefly the two particulars now mentioned; and, notwithstanding the terror with which, in the imagination of many young painters, the study of it is clothed, by reason of the mathematical difficulties with which it has usually been mixed up, it is in itself simple. A student can scarcely make a more instructive experiment than to take a framed drawing or engraving of a view from some window, and having set it up near the window, to place by its side an empty frame of the same size. By then comparing the reality, viewed as a picture, through the empty frame, with the true picture fixed in the other, their perfect accordance becomes very striking in regard to the sizes, positions, and shadings of the parts, all illustrating the rules of perspective. Although, without a knowledge of these rules, a quick eye soon enables its possessor to sketch from nature with much truth; and although the two instruments, the *camera obscura,* already described, and *camera lucida,* to be described in a future page, give almost mathematical accuracy to drawings made with their help, without requiring other skill in the draughtsman than to trace and make permanent, with ink or pencil, the lines of light which he sees on the paper; still the subject is so interesting to all who attempt to sketch, and, indeed, to all who wish to look intelligently either at nature or at works of art, that none who have the opportunity of studying it should neglect the study.

1093. Supposing straight rows of similar objects, as of the stone blocks or pillars or houses represented here from *a* or *b* to S, to run directly south, and to be viewed by a person stationed at a window over the point C, between and near the end of the rows forming the street *f*, *d*, then, because, as already explained, objects to the eye appear smaller in proportion to their increased distance from it, the second block, if twice as far off as the first, would appear only half as large; the third, if three times as far, would be only one-third as large, and so on to any extent, and for any other proportions; and if the thousandth or any other block, owing to its distance, subtended to the eye an angle less than the sixtieth of a degree of space in the field of view, it would be altogether invisible (as explained in Art. 1081), even if nothing intervened between it and the eye. And for the same reason for which the size of the blocks would appear smaller, the distance between corresponding or opposite blocks in the two rows would appear less and less, until the rows would seem to meet. Then, where the rows and the blocks cease to be visible from the minuteness of the parts and distances, and from the fact of the nearer ones concealing those farther off, they are said to have reached their *vanishing point.*—When a student of perspective has learned what regards the vanishing *point* in relation to sizes, distances, and positions of objects, he has learned half of his art. The above cut is to be considered as the representation of a street, running directly south to S, sketched from a window opposite to its end looking along its centre.



1094. It is important here to remark, that in any case of a straight line, or a row of objects thus vanishing from sight, as here the line or row *a* S, in whatever direction it lies from its beginning, whether east, west, north, or south, &c., in that direction, exactly from the eye of the observer, will its remote or vanishing extremity disappear. In this sketch the row *a* S is supposed to run directly south; and, although the eye, to see the beginning or near end of it, would have to look towards the left or east end, and to see the first block of the other row would have to look west, still every successive pillar would appear more and more towards the south, and the point in the heavens, or in a picture, or in a transparent plane before the eye, where the lines would vanish, would be exactly south from the eye. Then, similarly, if there were many rows of objects, as of pillars, houses, trees, &c., parallel to the first, but considerably apart from each other, as the lines here *a* S, *b* S, *d* S, &c., still all would vanish, or seem to terminate in the very same point of the field of view. The reason of this important fact may be thus again explained.—Let us suppose a line drawn directly south from the eye to the point S, between the parallel lines of pillars, houses, and trees, *a* S, *b* S, *d* S, &c., also pointing directly south, and let us suppose the two rows of pillars to be 100 feet apart, then evidently for the same reason as the space between the top and bottom of the pillars, that is to say, their height, becomes apparently less and less as their distance from the eye increases, so will the space between each pillar and its opposite in the other row, or between it and the point corresponding to it in the visual ray along which the eye looks, become *apparently* less, and therefore the lines of pillars really and everywhere 100 feet apart from each other, and 50 feet from the visual ray, will at a certain distance from the eye (*viz.*, where a space of 50 or 100 feet is apparently reduced to a point), appear to join, and the three lines will appear to meet in that point, beyond which none of them can be visible, and which is therefore the vanishing point of all.—It aids the conception of this truth to suppose a planet visible in the exact point of the heavens S, at the moment of observation; then, if the three parallel lines were continued on to the planet, and were visible all the way, they would arrive there with the interval between them just as when they left the earth; but as a planet, although thousands of miles in diameter, owing to its distance from the earth, appears on earth only as a point, much more would two lines only 100 feet apart be there undistinguishable in place by human sight. And what is true of a space of 100 feet between parallel lines, is equally true of a space of a mile or of thousands of miles. As a general rule, therefore, it holds, that all lines really parallel among themselves, when represented in perspective, tend towards, and if continued, end in, the same vanishing point—which point is the situation where the line terminates, along which the eye looks when directed parallel to any one of the real lines. And this is true not only of lines lying in the same level or horizontal plane, such as might be formed across a lake, but also of lines placed one above another, as those running along the tops and bottoms of the pillars here, or along the walls, roofs, and windows of the houses, or along the roots and summits of the trees, and indeed of all lines in whatever situation, provided they are parallel to one another, and therefore to the visual ray. And the truth holds equally with respect to short lines which do not reach the vanishing point, or centre of the picture, as with respect to those which do. When it is ascertained therefore that a line or boundary of any natural or artificial object has a certain inclination to the axis of the picture, or to what we have described as the principal visual ray, then also is it known that all the parallels to that line have their vanishing point in the same spot of the field of view, and a line supposed to be drawn from the eye into space, or really drawn from the eye to the picture in that direction, marks upon the picture or its plane extended, the true vanishing point of such lines.

1095. It will now be understood why, in a long arched tunnel, or a cathedral, with many longitudinal lines on its floor, walls, roof, &c., all such lines seen by an eye looking along from one end, appear to converge to a point at the other, like the radii of a spider's web; and why, similarly, in the representation of the interior of a common room, here sketched as viewed from one end, all the lines of the corners, tops and bottoms of windows, floor, stripes on a carpet, edges of tables, &c., being in reality parallel to one another, tend to the same vanishing point as V. The appearance of the lines in the floor of this room may recall that of the furrows in a ploughed field as seen from one end, when they appear like the ribs of a fan spread out towards the spectator. The same considerations will explain the phenomenon occasionally observed, of two small clouds seen near



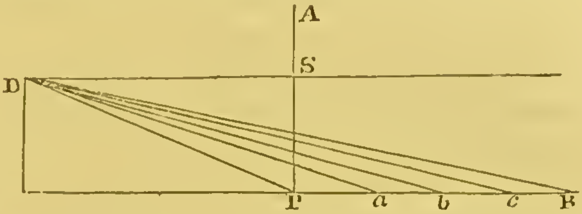
to each other, and almost motionless for a time in the distant sky, but which on approaching the spectator with the wind, appear gradually to enlarge and separate, so that one of them sweeps past considerably to the right hand, and the other considerably to the left: after this, they again contract in volume, and approximate as they were when first observed, and at last appear just as small and as close as when first observed. Because clouds are very mutable and uncertain in their forms, persons have been led to think all changes among them of apparent form, size, and place, to be real changes, and not, as they generally are, mere optical or perspective illusions from changing distance.

By far the most important vanishing point in common scenes is the middle of the line of the horizon, and in a picture properly placed it is at the exact height of the eye of the spectator. It is marked S in the figure before the last, and V in the last figure. Because in houses, the roofs, foundations, floors, windows, tables, and other furniture, &c., are nearly all horizontal, the vanishing points of their principal lines and surfaces must be somewhere in the horizon, and for most of them, near the middle of the picture. In holding up a picture-frame, through which to view a scene suitable for a picture, it is found most generally befitting to cause the line of the horizon to cross the frame at about one-third from the bottom of it:—this fact becomes the reason of the rule in painting, so to place the horizontal line of the picture. In beginning a picture, this line is usually the first line drawn on the canvas, as marking the place of the vanishing points of all level lines and surfaces. And the eye of the spectator is supposed to be placed before the middle of it, and generally about as far from the picture as the picture itself is long, such being the extent of view which the eye at one time most conveniently commands.

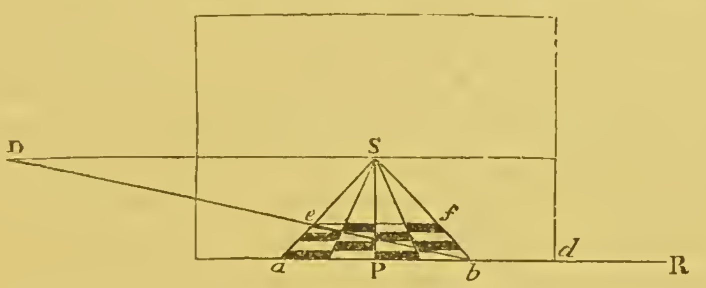
Understanding now that the apparent or perspective direction of all lines in a scene is towards their vanishing points, and the rule having been given for determining these points in a drawing, it is now to be inquired how much of a line drawn to any vanishing point belongs to the known magnitude of the object which it touches; in other words, how much an object is in perspective foreshortened in consequence of its distance and obliquity of position in regard to the eye.

1096. If we suppose A S P to represent a plate of glass standing edgeways, on which a picture might be painted, and that towards the point S in it, an eye is looking horizontally from the point

D; evidently then, a line from P continued in the direction of B and beyond, until vanishing from sight, would have as its perspective image or representation on the glass the line from P to S—S being, then, the *point of sight* in the picture, and the pictorial vanishing point of the line P B however far extended. Now, to divide the *representative* line P S so as to correspond with any given portions of the *original* line P B, &c., it would be necessary only to draw other lines from the place of the eye D to the line P B in the situations desired, and these lines would cut the perspective line S P in the proportions required. For instance, the portion of true line *a b* would be represented by that portion of the image line S P, included between the two lines *a* D, and *b* D, and so of any other portions.



1097. There are figures drawn on mathematical scales by which such problems as the above can be at once approximatively solved; and it would be possible by trigonometrical calculation to solve them exactly in all cases; but the most generally convenient mode in practice is to sketch on the intended drawing (as that of which the boundaries are given in the adjoining cut) the kind of measure required, by setting off from the point of sight S, a distance on the horizontal line, as at D, equal to the distance of the eye from the picture, and then by oblique lines drawn from D to the base line P R, to cut the perpendicular line P S in the situations desired. This is done in the last figure, which differs from the present chiefly in having the *point* of distance D, marked *before* its point of sight, instead of, as here, *laterally*. And the line P S being always cut by the oblique line from D in proportion to the length of base-line concerned between P and the extremity of the oblique line, a



horizontal line drawn through any point in the line from D, cuts in due proportions the other lines which have their vanishing points in the horizontal line at S, for instance, *a* S, P S, &c. Thus, to draw in perspective, on the surface above represented and prepared, a chess-board or board of squares, it is necessary to set off half the breadth of the board on the base-line to the right and left of P, *viz.* at *b* and *a*, and then to draw to the point of sight as a vanishing point, the lines *a* S and *b* S, part of which lines will therefore represent the sides of the board, and then to draw the diagonal D *b*, which for the reasons above stated will cut the lines P S and *a* S in proportion to the length of base-line to the right of their extremities; *a e f b* therefore is a square seen in perspective, and any number of smaller included squares are made by drawing lines from the vanishing points to equal divisions on the base, and making cross horizontal lines where the diagonal cuts these.

1098. Much of the delight which the art of painting is calculated to afford is lost to the world, because persons in general are not taught how to look at a picture. Unless a spectator place himself where he can see the objects in true perspective, so that he may fancy himself looking at the realities through a window or opening, everything must appear to him false and distorted. The eye should be opposite to the *point of sight* of the picture, and therefore on a level with the line of the *horizon*, and it should be at the required distance from the picture, which is generally at least as great as the length of the picture. It needs not to be said that fault of the artist cannot be remedied by any position of the spectator. It is very common, for instance, to see miniature resemblances of architectural structures so foreshortened and tapered, that the eye, to see them in true perspective, would require to be within an inch of the paper. These at the usual distance from the eye of ten or twelve inches are seen as hideous distortions. The specimens in the few preceding pages necessarily exemplify in a degree this error, because the *point of distance* had to be marked where there was but a small page. The figures, therefore, by any person studying the subject in detail, should be drawn on a scale so much larger, as to allow the eye really to view them at the distance supposed.

A means of judging of the dimensions of bodies by the visual angle, and which depends neither on the absolute size of the image, nor on the foreshortening of the ground plane on which the body stands, is, to use known objects in view as measures for others near them which are unknown.

1099. If a person of our acquaintance be standing at some distance from us near another person who is a stranger, we know how tall the stranger is by taking the acquaintance as a measure.

In pictorial representations of objects previously unknown, as to young people must at first be, the Egyptian pyramids, the bodies of the whale, the elephant, the camel, &c., human beings may be represented around them to serve as measures for the less known object. The Colossus of Rhodes seen from afar, might to a stranger have appeared but an ordinary statue of a man, but the exact magnitude would have been known as soon as a ship of known dimensions were seen sailing into port between his gigantic limbs.

When an unpractised eye is first directed from a distance to a great ship, it will on many accounts dwell upon the object with wonder and admiration ; but it may not judge truly of the enormous magnitude until it see another vessel of known size near to it, or can perceive the sailors climbing on the rigging, and appearing there, by comparison, as little birds appear among the branches of a lofty tree.

By having a measure of this kind presented to us, the magnitude and elevation of great edifices are rendered more obvious. The magnificent pile of St. Paul's in London becomes still more striking to persons passing by, when they discover visitors looking from the balconies near the summit-cross. These appear so minute among the surrounding huge masses that for a while a spectator is disposed to doubt whether they can be full-grown men.

Many persons cannot distinguish between the little pilot balloon (sometimes despatched before a great one to show the direction of the wind) and the great balloon itself, until under the last they perceive the aëronauts as little black objects in the basket.

Strangers visiting Switzerland, on first entering a great valley there, are often much deceived as to its extent. Being familiar generally with more lowly hills and shorter valleys at home, which, however, from being near to the eyes, form bulky images, and having at first no other measure of comparison, they almost universally underrate the Alpine dimensions:—they will wonder, for instance, in the valley of Chamouny, that they should be travelling swiftly for hours without seeming to approach the end.

1100. The author, in sailing past the Canary Islands, had a view of the far-famed Peak of Teneriffe. It had been in sight during the afternoon of the preceding day, at a distance of more than 100 miles, disappointing general expectation by appearing then only as an ordinary island rising out of the ocean; but next morning, when the ship had arrived within a shorter distance, and while another ship of the fleet, of seventy-four guns, holding her course six miles nearer to the land, served as a measure, it stood displayed as the most stupendous single object which most of the eyes on board had ever seen. The great ship in question appeared but as a speck rising from the sea, when compared with the huge prominence beyond it towering sublimely far above the clouds. Teneriffe alone of high mountains, rises very directly out of the bosom of the ocean, to an elevation of 13,000 feet, and as an object of contemplation, therefore, is more impressive than even the still loftier summits of Chimborazo or the Himalayas, which rise from elevated plains, and in the midst of other heights only a little less elevated than themselves.

It is because objects which are nearly on a level with us, as contrasted with such as either rise much above or fall much below, are usually surrounded by other known objects which serve as measures of comparison, that we judge so much more correctly of the size and distance of things near our level than of others.

1101. A man walking like ourselves on the sea-shore or other level, may be recognized at a considerable distance; and probably it may not occur to us, that he appears much smaller on account of the distance; but if the same man be seen afterwards at an equal distance above us, collecting the sea-fowl's eggs on the face of a cliff, or if afterwards, when we have ourselves reached a height, we see him gathering shells on the beach, he appears no bigger than a crow: yet in both cases he is where the same bulk forms the same magnitude of image on the retina.

Even on a horizontal plain, if the general surface be bare and uniform, single distant objects appear very diminutive. This is true, for instance, of a man seen apart from his caravan, while journeying across a flat desert; but a man viewed at an equal distance, in the midst of a cultivated landscape or among any known objects, appears of his natural size. The same is true of a single boat or ship seen out on the high sea, as contrasted with like objects viewed in a crowded harbour.

1102. We may now understand why the sun and moon, at rising or setting, appear to us much larger than when they have attained meridian height—although, if we examine them by any precise measure of the visual angle, as by looking at them through a known ring or tube, we find that there is no difference. The sun and moon as they appear from this earth are nearly of the same size, each occupying in the field of view about the half of a degree, or as much as is occupied by a circle of a foot in diameter when held 125 feet from the eye—which circle therefore at that distance, and at any time, would just hide either of them. When a man first sees the rising moon apparently filling up the end of a street, which he knows to be 100 feet wide, he naturally believes that the moon then subtends a greater angle than usual, but the reflection may occur to him, that he is using as a measure, a street known indeed to be 100 feet wide, but of which the part concerned, owing to its distance, occupies in his eye a very small space. The width of the street near to where he stands may occupy sixty degrees of his field of view, and he might there see from between the houses broad constellations instead of the moon only, but the width of the street far off may not occupy, in the field of view, but a small part of one degree, so that the moon, which always occupies half a degree, will there appear comparatively large. The kind of illusion now spoken of is yet more remarkable when the moon is seen rising or setting beyond still larger known objects,—for instance, beyond a distant hill or island, which appears all within the luminous circle. Any person who from Greenwich Park has observed the sun setting beyond London, with St. Paul's Cathedral included within its circumference, will recollect a very interesting example of this kind. Another example is afforded by the case of a balloon at a great elevation seen crossing the disk of the sun or moon, and then appearing, however large in reality, as an absolute speck within the vast luminous area.

1103. It may be remarked here, that the visual estimate formed of the great size of the sun and moon when seen on the horizon, is not an illusion, as was at one time popularly supposed, but an approximation to truth, only prodigiously short of the reality. When a distant tree, or a house, or a hill is seen, apparently within the circumference of one of these orbs, it is really as true that the orb is larger than the tree, or house, or hill, as that a distant hill, similarly surrounding by its outline a nearer hill, would be larger than that; but the celestial body is so much larger than anything interposed on earth, that even if the whole of Britain could be lifted away from the earth, and suspended near the moon, as a map in the sky, it would hide from a spectator on earth but a small part of the disk beyond.

Having now shown that the visual angle or apparent size becomes a measure of the distance of any object, only when the true size is known, or of the true size only when the distance is known, we proceed to examine other means which the eye possesses for estimating distances.

2nd. *Intensity of light, shade, and colour.* (See the Analysis, pages 497 and 541.)

It has already been explained that light, like every other influence radiating from a centre, becomes rapidly weaker as the distance from the centre increases, being, for instance, only one-fourth part as intense at double distance, and in a corresponding proportion for other distances; while it is still farther weakened by the obstacle of any transparent medium through which it passes. Now persons soon become sufficiently familiar with these truths to judge from them, with considerable accuracy, of the comparative distances of objects.

The Gothic pile of an ancient cathedral may break upon the view in some situation where nearer edifices, and perhaps some minor imitations of its beauties, already fill the eye with their strong lights, but the misty or less distinct outlines of the venerable pile warn the approaching stranger of its true magnitude, and prepare him for the enjoyment which a nearer inspection of its grandeur and perfection is to afford.

A small yacht or pleasure boat may be built according to the same model or with the same comparative dimensions as a first-rate ship of war, and may be in view from the shore at the same time, only so much nearer than the ship, that both shall form images of the same magnitude on the retina of a spectator. In such a case, an unpractised eye might have difficulty to discriminate, but to an old seaman, the bright lights of the little vessel, contrasted with the softer or more misty appearance of the larger, would declare the truth at once. A haziness occurring in the atmosphere between the little vessel and the eye, might considerably favour the illusion.

In a fleet of ships, if the sun's direct rays fall upon some here and there through openings among the clouds, while the others remain in shade, the former in appearance start towards the spectator. In like manner, the mountains of an unknown coast, if the sunshine falls upon them, appear comparatively near, but if clouds again intervene, they seem to recede, mocking the awakened hope of the approaching mariner.

1104. A conflagration at night, however distant, appears to spectators generally as if very near, and inexperienced persons often run towards it with the hope of soon arriving, who find after miles travelled that they have made but a small part of the way.

A person ignorant of astronomy deems the heavenly bodies vastly nearer to the earth than they are, merely because of their being so bright or luminous. The evening star, for instance, seen in a clear sky over some distant hill-top, appears as if a dweller on the hill might almost reach it—for the most intense artificial light which could be placed on the height would be dim to a distant spectator in comparison with the beauteous star; yet to a dweller on the hill it appears just as distant as to one on a remote plain.

The concave of the starry heavens appears flattened above, or as if its zenith were nearer to the earth than its sides or horizon, because the light from above having to pass through only the depth or thickness of the atmosphere is little obstructed, while of that which comes towards any place horizontally through hundreds of miles of dense vapour-loaded air, only a smaller part arrives.

The sun and moon appear larger at rising and setting than when midway in the sky, partly, as already explained, because they can then be easily compared with other large objects, of which the size is known, but partly, also, because of the much less light arriving from them in the former situation, while their apparent diameters remain nearly the same.

1105. A fog or mist is said to magnify objects seen through it. The fact is, that because it diminishes the intensity of the light from them, it makes them appear more distant without lessening the visual angles subtended by them; and because an object at two miles, subtending the same angle as an object at one mile, is twice as broad, the conclusion is drawn that the dim object is large. Thus a person in a fog may believe that he is approaching a great tree, fifty yards distant, when the next step throws him into a low bush which had deceived him. Two friends meeting in a fog, often mistake one another for persons of greater stature than theirs. There are, for similar reasons, frequent misjudgings in late twilight and early dawn. The purpose of a thin gauze screen interposed between the spectators in a theatre and some person or object on the stage meant to appear distant, is intelligible on the same principle: a boy near, so screened, is meant to appear a man at a distance. The art of the painter uses sombre colours when his object is to produce in his picture the effect of distance. On the alarming occasion of a very dense fog coming on at sea, where the ships of a fleet are near to each other, without wind, and where there is considerable swell or rolling of the sea, much damage is apprehended.

1106. The celebrated *Spectre of the Brocken*, among the Hartz Mountains, is a good illustration of the present subject. On a certain ridge, just at sunrise, a gigantic figure of a man had often been observed walking, and extraordinary stories were related of him. About the year 1800, a French philosopher and a friend went to watch the apparition; but for many mornings they paraded on an opposite ridge in vain. At last, however, the monster was seen, but he was not alone; he had a companion, and singularly, he and his companion aped all the motions and attitudes of the two observers: in fact, the spectres were merely shadows of the observers, formed by the horizontal rays of the rising sun falling on a morning fog which hovered over the valley between the ridges; and because the near shadows were very faint, the figures were deemed distant, as of gigantic men walking on the opposite ridge. A comparatively small figure seen near, but supposed distant, appears of gigantic dimensions.

1107. While the different intensities of light coming from bodies considered as wholes, furnish an indication of their different distances from the observer, the comparative intensities from their sides unequally exposed to the sources of light, and therefore illumined or reflecting light to the eye, in different degrees, indicates the forms and attitudes of the bodies. In observing, for instance, a white house exposed to the sun, it is seen that the side receiving the rays directly is highly illumined or bright, while the other sides are much less so, and are said to be in the shade—a shade which is more or less deep in proportion as there are few or many sources of reflected light bearing on it. The different faces or walls of such a house are, to the sense of the observer, as strongly distinguished from each other, by the mere difference of shade, as if they were of different colours, or as if they were examined by the touch, or by walking round them. If the object examined were a ball instead of a square house, there would still be the great differences of shade in the parts not receiving direct rays, but instead of forming abrupt contrasts at corners like the walls of a house, they would appear to melt into each other, marking the beautiful round contour of the object. The consideration of all such cases forms the subject of light and shade or *chiaro-oscuro*, so interesting to the painter.

1108. Had there not been in nature the provision of light and shade, the sense of sight would have been of comparatively little use, and a mass of things in the light, if of the same colour, would have been as little distinguishable from one another by a person looking directly at them, as a mass of things are, in their common shadow formed on a wall. It is this provision, therefore, which enables us, independently of colour, to distinguish the profile or outlines of different bodies placed near to one another, and to distinguish in the same body the protuberant or hollow or other form of the surfaces which are towards the observer. But for this, it would have been impossible to distinguish, for instance, between a white wall when bare and when having various white objects placed upon or before it; and it would have been impossible to distinguish clearly between the rounded figures of a flat circle, a sphere, and a cone, similarly coloured, and with axes pointing to the eye; but in reality, by differences of shade, the white objects are distinguished from the wall, and in the three geometrical figures mentioned, the uniformly bright surface of the circle, the soft rounded shadowing of the sphere, and the shade coming to a point on the cone, at once declare the true forms. But for the shadowed parts, the façade or front of a white palace of curious architecture would have been an unmeaning sheet of light; the lights, however, and shadows produced by the juttings and recesses, mark the variety of surface very completely; the round pillar is distinguished from the square, and every pediment, and capital, and architectural ornament, stands out pleasingly conspicuous. But for light and shade, again, the "human face divine" would have been a uniform unmeaning breadth of flesh, instead of having the differences produced by different exposures to the light, which cause every prominence and depression, and every momentary change, to be so truly indicated to the eye that it becomes full of meaning or expression. How well mere light and shade serve to convey what the eye has to learn of a scene or object, may be perceived by examining any of the admirable engravings which now abound, and which, although made up entirely of degrees of shade, or of black and white, are scarcely inferior in expression to finished paintings.

The student of painting soon learns that the hard tracings called outlines, by which he first sketches subjects, do not exist in nature, and have to be again effaced in his finished work: for they only mark the place where lights and shades happen to meet. Much may be conveyed to the mind, however, by a mere outline, and particularly if lines of different breadth or thickness are used to indicate the situation of the fainter and deeper shadows.

The subject of chiaro-oscuro is not so simple as, from the fact of the sun being the great source of light, might at first be supposed; for although this be true, still every body which reflects the sun's light becomes a new source to the bodies around it, and the shading of a picture must have reference to all such sources, and to the different colours of the body itself, and of the neighbouring bodies.

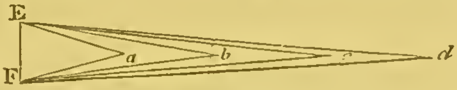
1109. In looking at an extended landscape, it is seen that the near objects, or those in the foreground, are comparatively bright, with their shadows strongly marked, and their peculiar colours everywhere easily distinguishable—as of flowers, fruit, foliage, &c., but of objects farther off and apparently diminished in size, the colours, with increasing distance become dim, the lights and shadows melt into each other or are confused, and the illumination altogether becomes so faint that the eye at last may see only a certain extent of sombre mountain or plain —appearing bluish, partly because the transparent air through which the light must pass has a blue tinge, and partly because the quantity of light which can pierce the great extent of air is insufficient to exhibit the detail. The ridge called Blue Mountains in Australia, another of the same name in America, and many others elsewhere, are not really blue, for they possess all the diversity of scenery which the climates can give, but to the eyes which first discovered them, and viewed them from a distance, they all at first appeared blue, and they have retained the name.

1110. In a good picture where, upon canvas stretched on a frame, the artist has disposed the lights, shades, and colours in the very situations and with the intensities which they would have had if coming from the real scene to the eyes, through a plate of glass filling up the frame, all that we have now been saying is strictly exemplified. In the foreground the objects are large and bright, but as they are supposed to become gradually more remote, the size and brightness correspondingly diminish, until at last there is only a dim mixture of bluish or greyish masses forming the boundary of horizon and sky.

1111. A child, during what may be called the education of the sense of sight, has a strong perception of the vast differences of appearance which things assume according to their accidental distance from the eye, their position, their exposure to light, &c.; for many of these differences, being at first calculated to deceive the young judgment, have from time to time been noted and recorded. Thus a boy when he first discovers that a ship which at the near quay, with her sails outspread, concealed from him half the sky, is in an hour or two afterwards seen by him on the distant horizon as a dark speck hardly big enough to hide one star,—has his attention strongly awakened, and he feels surprise; or again, when he learns that the faint blue unchanging mass which he had always observed bounding in one direction the view from the home of his youth, is a distant mountain-side thickly inhabited, and covered with dwellings and gardens, where in succession the bright colours of the different seasons periodically glow—he is equally struck. But as soon as experience has enabled him to interpret readily and correctly the visual signs under every variety of circumstance, his attention passes so instantly from them to the realities—just as it might pass from the paper and printing of a newspaper to the important intelligence communicated by them, that he very soon ceases to reflect that the sign, which in every case similarly suggests the object, is not also in every case like the object, and the same true and complete representation of the reality. The feeling that the sign must be like the thing suggested, becomes at last so strong, that even a difficult effort has to be made by a grown person again to attend to the mere *appearances*, in any scene of which the *realities* are known.

1112. This attempt to analyze visual appearances, and to estimate truly their connection with realities, is called, as already stated, the study of *perspective*. When it regards the apparent reduction of size, and the foreshortening of bodies under various circumstances, it is called *linear perspective;* when it regards the fading of light and the modifying of colour, it is called *aërial perspective*. As the advanced art of painting depends so much upon the understanding of these two departments, the gradual progress which it has made in different countries is a measure of the degree in which the common prejudice that things *appear* exactly as they *are* has in them been overcome. Where this feeling exists, any untaught person conceives a good painting to be merely a miniature representation drawn according to a certain reduced scale,—as of an inch to a yard,—and in which all the dimensions of things should be measurable as simply as in the reality—while the colours as to vividness, &c., should perfectly agree with the originals. This statement is remarkably illustrated by the facts, that children in their rude attempts to paint, always aim at realizing such notion of the art, and that such has been the first stage of painting in every country. In Europe now, owing to the labours of men of genius, art in painting may be said almost to rival nature, producing impressions on the retina as vivid as those from nature's own scenes, and scarcely distinguishable from them: but in other countries, as in China and India, among the native artists, the early stages of the art may still be studied. In many Chinese pictures, owing to the absence of perspective proportions, an extensive subject is only a collection of portraits of men and things drawn nearly on the same scale, and placed one above another, and where all the colours are as vividly shown as if the objects were only a few feet from the eye: the figures at the bottom or foreground are meant to represent the objects nearest to the spectator, while the figures higher up are supposed to be of more remote objects, all appearing as they might be seen in succession by a person who had the power of flying over the country. This kind of representation, although not natural if all viewed at once, may communicate more information than a single common painting, for it is equivalent to a succession of such. In Europe lately the principle has been usefully acted upon for certain purposes, as for representing on one long sheet or on a succession of sheets connected in a suitable manner, the banks of a river or a line of road. The banks of the Rhine particularly have thus been admirably portrayed, so that the spectator directing his eye along the paper, feels almost as if carried in a balloon to view in detail the whole of the enchanting scenery. The bird's-eye view of the ancient city of Cologne, with all its famed architecture and its noble modern bridge spanning the great river, is a portion of such representation.

3rd. *Divergence of the rays of light.* (Read the list at page 541.)

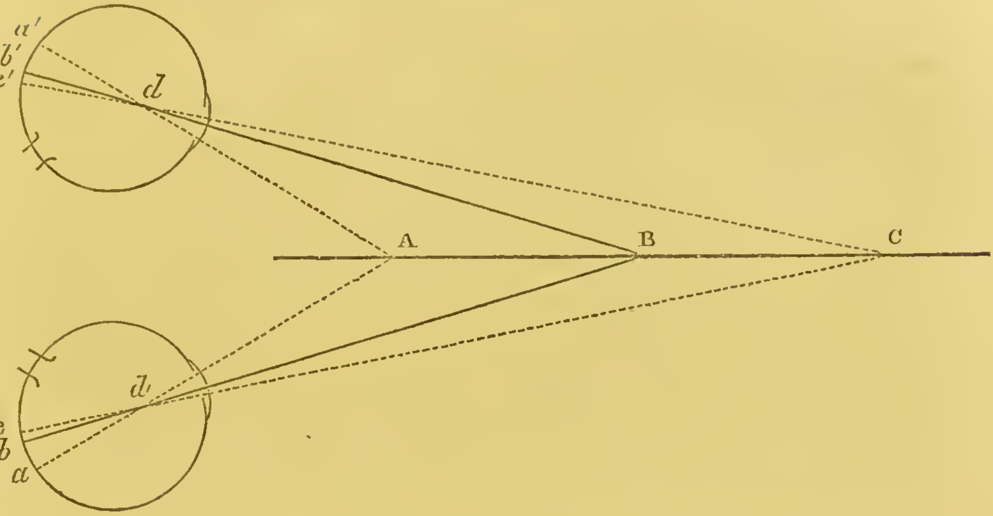


1113. This is the next circumstance to be mentioned by which the eye judges of distance. Supposing the line E F to mark the place and breadth of the pupil of the eye, the light entering from an object at *a* which is near (it is here placed nearer than an object could be seen in reality), is very divergent, or is spreading with a large angle; from *b* the pencil of rays is less divergent, or opens with a smaller angle; from *c* it is less divergent still, and so on. Now the eye to form an image on its retina requires to exert a bending or converging power exactly proportioned to the divergence of the received rays; and the person has a sense of the effort made, which becomes a kind of measure of the distance of the object. This divergence of the rays entering the eye, is an important circumstance in which the most perfect painting must still differ in its effect upon the eye from a natural scene, —for, first, in the natural scene, most of the objects are more distant than their representation can be; and, secondly, while in nature every object according to its distance is sending rays which reach the eye with corresponding divergence, the rays from a picture, which is a single plane surface, come from every part with nearly the same divergence, the eye must feel, therefore, a disappointment in not having to accommodate its power of bending to the different distances attempted to be portrayed on the canvas. It might be expected that this kind of disappointment would be more felt on looking at a common picture placed a few feet from the eye, than at the sort of picture called panorama, which is on a larger scale and proportionately more distant, but such is not always the case. The reason seems to be, that in the former the illusion is not assumed to be complete, for the fact of its being but a picture is not at all concealed, and the eye is therefore at once told to expect a difference of feeling ;—but in the panorama, the various circumstances are arranged to deceive the eye, if possible, entirely, and to make the spectator believe that the images on the retina are formed by light from the objects themselves. Then to the eye really deceived in all other particulars, the non-accordance with nature in this one is quickly, and by some persons even painfully felt, so as on their first entering the place to occasion slight headache or giddiness. The illusion and consequently the pleasure from viewing pictures of distant objects, may be made more complete by the spectator using a single lens or a pair of spectacles, of focal distance, nearly equal to the distance of the picture from the eye ; because such lenses, as already explained, would render all the rays entering the eye nearly parallel, and therefore very nearly such as would reach it from objects at a considerable distance.

4th. *Convergence of the axes of the eyes.* (See the list at page 541.)

1114. This is the last circumstance to be considered, by which a person, through the eyes, judges of the distance of objects. In consequence of there being two eyes, on the centres of whose retinas light from any object must fall, that the person may have clear vision of it (1061), the axes of both eyes must be directed to the same point of the object. If it be very near, the optical axes will meet and cross each other very near to the face, exhibiting to bystanders the appearance called squinting, as when a man tries to look at the point of his nose ; but for objects at greater and greater distances, the optical axes will become less and less oblique, until at length they are nearly parallel to each other. This state occurs, also, when persons are thinking of things not present, and, therefore, seen only by the mind's eye ; and the countenance is, then, said to express contemplation or thoughtfulness. The following figure serves to explain this part of the subject.

1115. The two circles represent the eye-balls, looking along a middle line A B C directly in front. That line is fitly realized by a common yard measure, or a straight lath of wood, having three pins sticking in it at different distances, as A B and C. While the axes of the two eyes are directed to the object at A, they form at meeting, a large or squinting angle, indicated by the letters *a* A *a′* : when they meet at B, the angle *b* B *b′* is smaller, or more acute: when they meet at C, the angle *c* C *c′* is smaller still; and the different degrees of



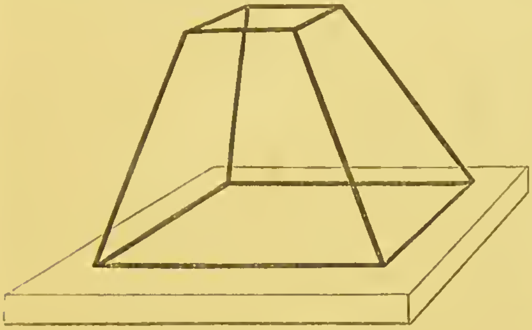
effort made to produce the necessary convergence, at the several points, of which effort the person is as conscious as of that exerted to bring the hands together, to examine by touch an object in the dark, becomes a measure, to a certain degree, of the distances. There occur at the same time these other facts. While the eyes are directed to the pin at B, seeing it clearly and singly, by the rays indicated here by the strong lines B *b* and B *b′*, they are receiving, also, from the more distant pin at C, rays of light indicated by the dotted lines C *c* and C *c′*; but the spots of the retina, *c* and *c′*, not being corresponding points (1061-2), give the sensation of two images formed on less sensitive parts of the retina, and they are scarcely noticed. Then, further, the eyes are admitting light, also, from the pin at A, nearer to them than the object at B, which light reaches the spots of the retina, *a* and *a′*, also non-corresponding points, on which two other indistinct images are formed. Thus, in any case of vision, the object on which the axes of the eyes meet is alone seen single and distinct, while any other objects at greater or less distances within the field of view, are seen double and indistinct. This is strikingly seen by looking along the rod and pins above described. It follows, of course, that the rod itself appears as two rods, except at the point supporting the object, to which the eyes are specially directed, and there the two appear to cross each other.

1116. A still simpler experiment than that above described, is, to hold up a finger a few inches from the eyes, and while looking steadily at it, to attend to the more faint appearance of things farther off, or nearer, as a book, a picture, a candle. These all appear double. If two fingers be held up in a line, at different distances from the eyes, the one looked at directly is always single and clear, the other always double and indistinct. In reading printed or written characters, a person sees distinctly at one time only three or four letters, because only these are sending light to a true focus in the centres of each retina; but the other letters, immediately around, although indistinct, do not appear double, because they are so nearly at the same distance from the eyes as those well seen, and have their images on points of the retina which correspond.

1117. In the last two paragraphs we have the means of explaining the singularly interesting invention of Professor Wheatstone, made about thirty years ago, and called by him the *Stereoscope* (στερεος, solid; σκοπεω, to see), another fruit of the same rare sagacity and exhaustless mechanical ingenuity which first devised and constructed for the world the working Electric Telegraph.

As the eyes judge of the distance of larger objects around the person, by the degree of convergence of their axes, required to give perfect vision of these, so do they judge of the size and shape of single solid bodies, which may be regarded as collections of minute parts or points joined together, by the angles of convergence required to see clearly the relative distances of the different points.

1118. Consideration of the following experiments, brings the important particulars under review. Let Fig. 1 represent a solid outline formed in wire, of a small pyramid, of which the top is wanting, placed on a block A B. If a person look directly down upon this with one eye, it will have the appearance of No. 2, with perfectly equal sides, and equal angles all round, and with the small square *a b c d* in the middle of the large one *e f g h*. If it be then placed midway before the eyes, that is, opposite to the middle of the face, the right eye alone looking at it, will see the sloping surface of the right side more directly than that of the left side, and the appearance to that eye will be, as shown in Fig. 4, the small square *a*, *b*, *c*, *d*, appearing no longer in the middle of the larger, but nearer to the bottom line *e g* on the left side. If, then, the left eye alone be directed to the pyramid, it will appear as represented in Fig. 3, with the small square near the line *f h*, on the right side. If a pane of glass, therefore, coated with gum, were placed between the eyes and the models, Figs. 3 and 4, and the view for each eye were traced on the glass, as described in Art. 1084, the tracing would be an exact counterpart of what is shown on this paper. This explains that two eyes cannot receive exactly similar images on each retina, at the same time, from the same solid body. By comparison, however, of the different images, a judgment is quickly made of the true form and position of the body. The experiment described may be made at once by setting up on edge between the two figures, Nos. 3 and 4, equally exposed to the light, a large card or a thin volume, so that when the eyes approach to within ten inches, each can see only the one drawing before it. The eyes, then, after a little practice will see, not the two drawings, differing from each other, but a single very perfect representation of the pyramid of solid wire, of which the upper part will appear clearly to be, at least an inch nearer to the eye than the bottom.



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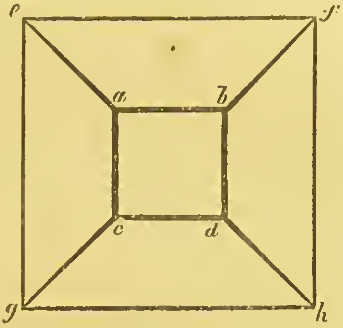

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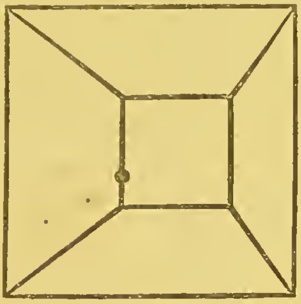

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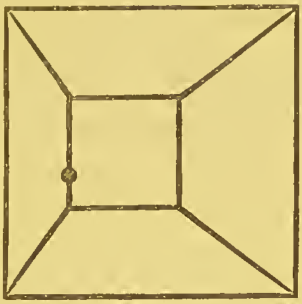


No. 3.

1119. To say that two eyes viewing the same object have on their retinas images differing from each other, according to the laws of perspective, just as in two camera-obscuras placed side by side, like the eyes, pictures of the same object differ—and that the images in the eyes coalesce in some way, so as to give to the person a clear perception of the solidity and shape of the object—to say this, is to state the fact, not to explain. If it be added, however, according to the details given in Art. 1116, that the two eyes see at one time, singly and clearly, so as to judge of its distance by the required degree of convergence of the optical axes, only the one point of the object then looked at, while the other points appear indistinct or double, and that by then changing quickly the direction and convergence of the axes to the other points, the distances and positions of all are noted; the explanation which was wanted is given.

For stereoscopic representations two pictures are required. To draw these correctly, according to the principles of perspective for complex objects, such as landscape or the human countenance, is so difficult, that if the camera obscura and photography had not been invented, which give such drawings at once, the stereoscope would have been little used. The eyes find the two views required of an object, presented in the object itself, and therefore in the same place. The two views made for the stereoscope are caused to be seen as if together or mingled, by mirrors or by lenses—the one stereoscope is called the reflecting, the other the lenticular, as will be explained hereafter. By reversing the position of stereoscopic pictures from right to left, the protuberant parts of objects appear depressions and *vice versâ.* The prominent pyramid above sketched, if so used, will appear a hollow or cave of like shape. Such change is called *pseudoscopic* (ψευδης, false).

1120. When a picture on a plane surface has to represent objects supposed far from the eye, the farther the picture itself is placed from the eye, supposing the figures to be made of size duly proportioned, the more nearly perfect will the illusion become, because the divergence of rays and convergence of the axes (two circumstances in which the effect of a mere picture on the eye must always differ from the effect of a real scene) will be more nearly what occurs in nature. This explains in part why the picture called panorama (from Greek words, signifying a *view* of *the whole*) is an exhibition so pleasing. The painting is removed to a considerable distance from the eye, and the near objects are drawn on a proportionately large scale, causing the eyes to feel that the light comes from a considerable distance, and that their axes do not need to approximate or converge much. When, in such a case, the first impression of the want of absolute conformity to nature has passed away, the illusion becomes nearly complete. Another important peculiarity in the panorama is, that instead of being a painting on a plane surface like common pictures, of which the sides are more distant from the eyes than the centre, and which embraces only a small part of the whole sphere of view, it is on a curved concave surface entirely surrounding the spectator, and on which all the objects visible in various directions from the supposed point of view, are seen in the very situations which in nature they hold; and the spectator is enabled to conceive much more distinctly of each particular by seeing it in relation to the others around. Few persons can forget the vivid impressions of surprise and pleasure made on them by the first panorama which they visited; and after increased experience and more enlightened judgment, they will discover still additional reasons for admiring this marvellous mode of being instantly transported to any distance, to contemplate at leisure some interesting scene represented under the most favourable circumstances of point of view, light, and weather.

1121. It corrects slight remaining optical defects of a common panorama to view it through a large lens, of which the focal distance is equal to the distance of the picture from the eye. This has the effect of diminishing the divergence of the luminous rays until it becomes exactly what belongs to the supposed remoteness of the objects, and it also bends the whole beams of light so that the axes of the eyes may be nearly parallel. The author has found it a convenient mode of using the large lens for such a purpose to be, to cut out two pieces of the size of common spectacle glasses from opposite sides of it, and to mount them as a pair of spectacles. From one lens three or four pairs may be formed.

1122. The effects of the magnitude and distance of the ordinary large panoramic views may, with the assistance of suitable glasses, be obtained from even a very small picture or engraved representation embracing the same field. An enterprizing artist might undertake to offer for sale a variety of such views at little cost. A common panorama picture, covering a circular wall of 100 feet in circumference and many feet high, may be reduced, still retaining the same truth of proportions, to appear as an engraving on paper five feet long and eight inches high. With the art of lithography, now so well adapted for producing soft representations of scenery, the expense of such views might be rendered so moderate as to allow of their becoming a common part of library furniture. When we reflect upon the expansion of thought obtained by travelling, and that not a few of the advantages of travelling would follow a familiarity with a good selection of panoramic views, it appears that courses of instruction in geography, history, &c., may be more commonly illustrated than now, by this very interesting mode of aiding the conception and memory.

Common paintings and prints may be considered as detached parts of a panoramic representation, showing as much of that general sphere of vision which always surrounds a spectator, as can be seen by the eye kept in one place, and looking through one window or other opening of moderate size. The pleasure from contemplating these is much increased by using with them a lens or such spectacles as above described.

The stereoscopic views, now become common, surpass all other representations of real scenes in being mathematically accurate, and in the curious fact, due to the double pictures, that objects behind hidden from one eye by objects in front, are visible to the other eye.

1123. A very interesting kind of representation has been exhibited in London and Paris under the title of *Cosmorama* (from Greek words signifying *sights of the world,* because of the great variety of views). Pictures of moderate size are placed outside of what appear ordinary windows in a darkened room, but which are really large convex lenses fitted to correct the errors of appearance which the nearness of the pictures beyond them would else produce. Then by the addition of various subordinate contrivances, calculated to aid and heighten the effects, they lead even shrewd judges to suppose the pictures of moderate size behind the glasses to be large elaborate works. To children they appear as magical realizations of natural scenes and objects.

1124. From what has now been said, it appears that for the purpose of representing still-nature, or mere momentary states of moving objects, a picture truly drawn, truly coloured, and which is either large to correct the divergence of light and convergence of visual axes, or if small, is viewed through a fit lens, would affect the retina almost exactly as the realities. But the desideratum remained of being able to paint motion. Now this too has been attempted, and in some cases with singular success, chiefly by making the picture transparent, and throwing lights and shadows upon it from behind. In the exhibitions of the Diorama and Cosmorama there have been thus represented with admirable truth such phenomena as the clear sunlight of a summer's day occasionally interrupted by passing clouds; the gradual rising and disappearing of a mist over a wide landscape; running water, as pouring down in the mighty falls of Niagara, or the still loftier cascades among precipices of Alpine regions; and even the appalling spectacle of a furious conflagration. In the Cosmorama of Regent Street, London, in 1830, the then recent great fire of Edinburgh was pictured with most telling effect. First, that noble city was dimly seen as in the gloom of midnight, but with an unusual light in one situation; flame soon appeared there, which rapidly grew into conflagration; at short intervals, as the wind increased, or as roofs fell in, there were bursts of flame towering to heaven, and strongly illumining every high wall or spire which caught the direct light—and the vast clouds of smoke ascending in rapid succession were borne away on the wind, to vanish in the distant darkness. So closely in accordance with nature was all this represented that persons who knew not Edinburgh were observed to be affected almost as if they witnessed a reality, while those who did know it, and had friends there, seemed to sympathize anew with the sufferers.—One part of the mechanism which produced these effects was a circular frame of canvas turning slowly as a wheel behind the main picture, on which canvas strongly illuminated from the back were painted forms of flame and smoke.

1125. It is remarkable, when the imagination is once excited by some striking pictorial view, how readily any additional visual hint produces clear and strong impressions. An attendant in the cosmorama reported one day—that a schoolboy visitor exclaimed with fearful delight that he saw a monstrous tiger issuing from a den among the rocks;—it was a kitten belonging to the attendant, which by accident had strayed among the paintings—and that another young spectator was heard calling out that he saw a horse galloping up the mountain side;—it was a minute fly crawling along upon the canvas. There is, in regard to pictures connected with motion, a wide field yet open to the exercise of ingenuity.

1126. Some years ago a picture, called a moving panorama, was displayed across the stage of a London theatre, which presented the appearance of about twenty miles of the southern bank of the Thames, as seen by passengers: a steamboat sailing down the river. The picture, necessarily of great length, was gradually unrolled from an upright barrel or spindle on one side of the stage, while rolled up on a similar barrel on the other side. A suitable description was audibly read, as the picture glided along, and the slow uniform motion produced on the spectators nearly the impression which the sailing motion of a ship might cause.—During several years, Albert Smith, in a small theatre, described his journey to Switzerland, and his ascent to the summit of Mont Blanc, illustrated by pictorial representations of the places and perilous incidents of his travel. Multitudes crowded to hear him and to see, and so successful was the performance, that visitors often said they could almost suppose themselves to have been of the travelling party. Other journeys have been similarly illustrated, as that over-land to India, that far across the continent of North America, and so forth. A moving panorama of kindred character, and aiming at effects still higher, has been attempted, viz., to depict the course of an individual human life. Scenes representing the principal events of the life were in succession made to glide across the field of view, and were so designed that the real motion of the picture gave to the spectator, the feeling that the events were in progress, and that he was present on the occasions. Some of the exhibitions above referred to might have been made more perfect in various respects, but in their mediocrity they served to prove how singularly adapted such unions of narration, painting and music are to affect the mind; and, therefore, to become means of conveying, to young minds particularly, impressive lessons of very useful kinds.

1127. Painting, whether employed to portray scenes of entirely still nature, or scenes involving some kind of motion, has as its aim or end to represent to the eye subjects of more or less interest, and to give to the spectator as much as possible that clear conception of them, which is obtained by ocular examination of realities. Thus, the visual signs of thought give powerful aid to language, or the audible signs, in expanding the boundaries of individual human existence into wider space and time, and thereby elevating human nature. It has always to be recollected, however, that what is usually dignified with the name of historical painting, really bears to historical truth only the kind of relation which novels and plays bear to it, and often approaches even less nearly to the truth; for it pretends to relate a thousand minute circumstances of which no history has been preserved, and which, therefore, only the imagination of the artist can suggest. Thus, when a painter, to recall that Lucretia stabbed herself in the presence of her father and others, after the crime of Tarquin's son, exhibits a beautiful young wife dying, and a certain number of persons around her in horror and astonishment, he no more represents the real Lucretia and her friends than he represents any other particular persons of the time: he is quite assured that not one of the figures in the picture is a portrait of the individual whose name it bears.—From all this it appears that historical pictures may often be regarded as portraitures, not of the realities, but of performers on a stage acting scenes in historical plays intended to give notions of the realities.

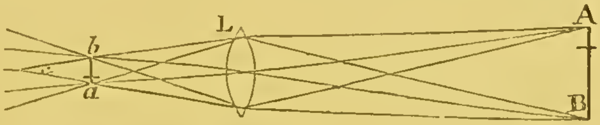
1128. The invention in our day of the stereoscope, and some other discoveries made regarding light and vision, as in photography, have added a new interest to this department of natural philosophy, and may lead to further improvements in the painter's art. Of many objects and subjects, knowledge can be conveyed more quickly and completely by pictorial images than by words, and as things differ so much in their nature, distinct classes of artists have arisen to represent them. There are special painters of flowers and fruit, of birds and of other animals, of landscapes, sea-pieces, the interiors of buildings, &c., and especially of the human countenance and form, singly in portraits and conjointly in scenes of human action as related in history. To attain moderate proficiency in some of these departments, moderate ability suffices, but to reach excellence in others, the highest natural endowments of intellect and feeling with educational cultivation are required. In public estimation, some of the great painters rank side by side with the great poets, and their names have become among educated people nearly as familiar as those of Homer and Virgil. It would be to go beyond the limits of the present work to dilate on this subject.

> "*When the image formed, as above described, beyond a lens, is viewed in the air by an eye placed still farther beyond in the same direction, the arrangement, according to minor circumstances, constitutes the* TELESCOPE *or the* MICROSCOPE." (Read the whole second paragraph of the Analysis, page 497.)

1129. The name TELESCOPE (a compound Greek term, signifying to *see far*, as *microscope* signifies to *see* what is *small*), applies to that marvellous instrument of comparatively modern invention by the use of which the intelligent mind may be said, on the beams of light as a path, to bound widely into space for the purpose of examining more closely the great distant bodies of creation; or, by which it seems able to command distant objects instantly to approach, for the purpose of convenient inspection. In ancient times, a man, while looking with admiration on the bright face of the moon, or of the evening star, might have exclaimed, "How pleased would I be, could I fly upwards to yon resplendent orb, the better to know its nature and beauties!" but he could little have anticipated that the day was coming when human ingenuity would find means in a great measure to satisfy the wish! The telescope is this means. One which merely doubles apparent diameter, shows the moon exactly as she would appear to a person who had ascended towards her from the earth through a distance of 120,000 miles, while one of greater power produces effects correspondingly great. But to examine the heavenly bodies is only one of the many uses of the telescope. The instrument fixed on the graduated brass circle of the theodolite, enables us to measure angles, which tell the exact distance of one mountain summit from another, even if a wide sea intervene; and men have often much interest to discover what is passing at a distance on the surface of the earth around them. Thus by a telescope, the military chief may obtain a close view of approaching friends or foes, while they are yet concealed from the naked eye, in the blue mist of distance; and similarly, the sea-captain, while persons around him perceive only a dark little speck on the far horizon, discovers that to be a ship of class and nation at once evident to him, and with the crew of which, by the additional use of signal flags, he is enabled readily to communicate.—At midnight, a telescope directed to a distant cathedral tower, may watch on the clock-face there, the motion of the hands marking the unceasing lapse of time. A man, placed in the midst of a wide plain, or on a lofty hill-top, or far on the face of a lake, who might suppose himself quite alone and unseen, might yet, through a telescope, be instantly placed under the observation of any one choosing to watch him. The same might happen to a man within the high walls of his own garden, or even within his house, near an open window, if a straight line could pass from him to an observer.

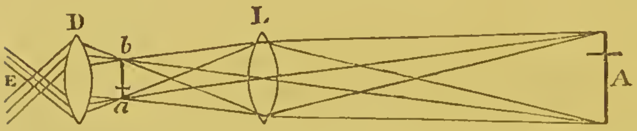
1130. Now the telescope, with its marvellous powers mentioned, exhibits but a modification of the simple case, described in Art. 1039, and exemplified in the camera obscura, &c., of an image formed for visual inspection, by the rays of light gathered to a focus beyond a lens. We have here to explain that its powers depend on the two facts, first, of its large lens collecting for the formation of the image (subsequently transferred to the observer's retina) a thousand times or more, the quantity of light which the naked pupil admits; and, second, of its forming by this light a large bright image, to which the eye may approach very near, to examine it through a magnifying glass of any power.

1131. To understand this fully, we must recall, as explained in Art. 1035, that the nature of the bending of light in passing through a lens is such, that all the rays reaching the lens from any point of a visible object in front (as the point A of the cross A B), and forming what is called a *pencil or cone of light*, are collected in a corresponding point, as *a*, at the focal distance beyond the centre of the lens, so as to meet the central ray of the pencil (here the direct line A *a*) ; and then, because the same happens to the light from every visible point of the object (the rays from only the two extreme points A and B are here represented), the collected light from all, if received on a white screen placed there, as in the camera obscura, make apparent to an eye looking from any direction a beautiful inverted image of the object. If no screen be interposed in the place where the rays meet to show this image, the rays, although not seen, are not lost there or disturbed, but merely cross in the air and pass on, diverging again beyond the focal points, or towards *c*, as they originally did from the several points of the object itself. An eye, there-



fore, placed beyond *c*, in the line of the rays must receive the light from every point of the image, and will see the image in the air as it would see an object situated where the image is. This fact is tested at once by holding a spectacle glass or any lens at a proper distance from the eye between an object and the eye. An inverted image of the object is seen.

1132. A telescope, then, is merely a tube, converted into a dark chamber by excluding useless light, and having a large lens, called the *object-glass*, filling its distant end like a window, through which the light from the objects in front enters, to form images towards the other end of the tube, where the eye may conveniently inspect them. The inspection of the image is made through another lens called the *eye-piece* of the telescope, which is fixed in a small tube made to slide backwards and forwards in the larger, so as to admit of the focal distances being adjusted to the power of different eyes, &c. The accompanying sketch in which, for the sake of simplicity, the external tube of the telescope does not appear, shows the progress of the light from points of the object A, through the object-glass L, to form an image at *b a*, and afterwards to be bent by the eye-piece D, so as to enter the pupil of the eye at E, where the rays cross, to form the last magnified image on the retina.



1133. In the simple telescope, having only two lenses, as above represented, and called the *astronomical telescope*, or sometimes the *night-glass*, when used by mariners at night, the image is inverted. This circumstance is of no importance in viewing the heavenly bodies, which are round, from whatever side seen. To fit the telescope, however, for viewing terrestrial objects, it is necessary to place in the tube another simple or compound lens, which shall turn the inverted image formed by the great object-glass into an image which is upright. There is considerable loss of light where it is necessary to multiply lenses.

1134. To determine how much larger an object will appear when viewed through a certain telescope,—for instance, through one with an object-glass of three feet focus,—than when viewed by the naked eye, we must recollect that the image is formed in the focus of the object-glass, or at *b a*, in the last figure, and subtends from the centre of that glass or lens, the same visual angle as the object itself, viewed from the same point (a fact explained in Art. 1049), and to an eye placed at the lens, would appear of the same size as the object; but if the eye be brought nearer to the image than the centre of the object-glass is, the image will appear in proportion just so much taller and broader, and thus, as compared with the object, may be called so much magnified. Now, as the naked eye cannot see distinctly an object nearer to it than at about six inches distance, because of the great divergence of light from nearer radiant points, the telescopo in question, without an eye-glass, would allow the eye to come only six times nearer to the image than when at the centre of the object-glass, and would only magnify the diameter six times; but if, then, an eye-glass, as D, of half an inch focus, be placed half an inch from the image, so as to render the rays of every pencil nearly parallel, and therefore accommodated to the power of the eye, an eye placed to receive in its pupil the crossing pencils, must see the image as large as if it were at half an inch from it, and therefore 72 times nearer than if viewed from the object-glass, and therefore, again, as of 72 times greater diameter. Now, as in all cases, the image in a telescope is in the focus both of the object-glass and eye-glass, and is therefore nearer to the latter than to the former in proportion as their focal distances differ, the magnifying power is measured by that difference—in the case at present supposed the difference is as 72 to 1, and 72 is the magnifying power of the telescope. The rule is generally thus expressed, "divide the focal distance of the object-glass by that of the eye-glass, and the quotient is the magnifying power." It is always to be remembered, however, that if the diameter of an object be magnified ten times, the surface is magnified as the square of the diameter, or 100 times, and so in proportion for other numbers. (See the Appendix.)

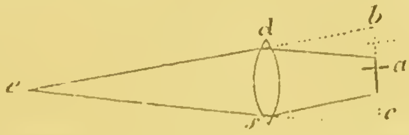
1135. With such means of aiding the sight then, it is, that we ascertain the light and dark patches seen by the naked eye on the face of the moon to be heights and depressions, or mountains and valleys, and can even measure the altitudes and depths of these; that we can see the four beautiful moons of the planet Jupiter; that we can perceive marks and irregularities on the surfaces of the other planets, enabling us to say at what rate they severally rotate on their axes, experiencing the changes of day and night as this earth does:—and that we can determine many other interesting particulars of like kind.

1136. The discovery of the telescope is said to have been first made accidentally by the children of a Dutch spectacle-maker, while playing with their father's work; but it was turned to no use until Galileo, led by science, experimented again, and being able to appreciate its worth, obtained from it the most sublime results. The human heart can rarely have throbbed with such delight as Galileo's when he first directed his optic tube to the heavens, and through it contemplated so many numerous objects before unseen by human eye!—as the changes in the planet Venus, our beautiful morning and evening star, which in parts of her orbit, appears not a circle, but a crescent, like our moon in her quarters—the satellites of Jupiter—the rings and satellites of Saturn—myriads of stars until then invisible to man; and in a word, when he beheld the irresistible proofs of the true system of the universe, as rare sagacity had before conceived it, uniting the greatest simplicity with unspeakable grandeur.

1137. The Galilean telescope was simply a large object-glass to collect much light, with a small concave eye-glass placed so as to intercept the converging rays before they reached their focus, and to change their convergency into the parallelism which the eye could command. This telescope, although magnifying so much less than that formed of two convex glasses, as above described, had still power to verify great fundamental facts in astronomy.

1138. It was explained in Art. 1031, that a beam of light in being much bent or refracted by transparent media, as by a strong simple lens, is also resolved into rays of the different colours seen in the rainbow. Hence an image formed beyond such a lens has coloured edges or fringes. This fact rendered the images of objects, in the first-made telescopes, if much magnified, indistinct; and, but for the important discovery made by Dollond the optician (Art. 1033), that different kinds of glass have *dispersive* and *refractive* powers of different relative force, so that a concave lens of a certain curve applied to a convex lens can completely counteract the dispersion of colours by the latter, while it leaves enough of the convergence of the rays for the formation of an image—refracting telescopes must have always been imperfect. Dollond called his telescopes *achromatic*, or *not-colouring*. It is remarkable, that he had the fortune to obtain some glass for his purposes more suitable than any which could with certainty be manufactured for years after.

1139. The so-called *single microscope* is merely a convex lens, and it magnifies, as already explained, chiefly by allowing the eye to be brought much nearer to the object than the distance at which the object could be seen without a lens glass: but even where the relative distance of the eye and object is changed, a lens interposed at its focal distance from the object will still magnify by bending the light, as seen at *d* and *f*, making that which comes to the eye at *e* from the top of such an object as the little cross *a*, to appear to come from *b*, and that from the bottom to come from *c*, thus causing the cross here represented by the black lines, to appear of the size represented by the dotted lines. A concave lens minifies for the contrary reason.



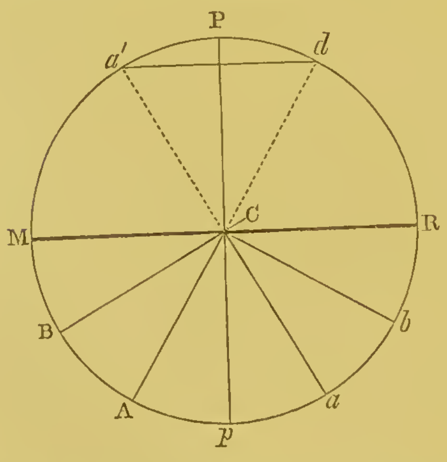
There are few greater gratifications for a person who has feeling for the beauties of nature, than to explore with the microscope. While the telescope lifts the mind to the contemplation of boundless space occupied by myriads of suns, and proves this globe of ours, as compared with the universe around it, to be little more than a leaf compared with a forest, or a grain of sand compared with what lies on the sea-shore; the microscope, on the other hand, excites wonder by showing on a leaf, or in a spoonful of water in which the leaf has been infused, thousands of living creatures, totally invisible to our naked eye, yet not imperfect because so small, but endowed with organs and parts as duly proportioned as those of an elephant. And he who has admired the orderly structure of a honey-comb, may look through the microscope upon a cut surface of wood to see minute arrangements still more wonderful: or he may compare the lace of an insect's wing with the most perfect fabric which human art can weave.

The telescope and microscope might both with some reason be called microscopes, for often the telescopic object, as a moon of the planet Saturn, from mere distance subtends, in the field of view, as small an angle as a minute animalcule. In such a case, the image in the telescope is a minute resemblance of a vast object at a distance; the image in the microscope is always an enlarged resemblance of a minute object or part of an object near. The microscope has been called the telescope reversed.

1140. The *compound microscope* of great power approaches remarkably, in its structure, to the *telescope*, but while in the telescope a large distant object forms in the focus of the large object-glass an image exactly as much smaller than itself as the distance of the image from the glass is less than that of the object,—in the microscope, conversely, a small object placed near the focus of a small object-glass produces a more distant image, as much larger than itself as the image is more distant than it from the object-glass,—and in both cases the images are viewed through an appropriate eye-glass. The object-glass in the telescope is large; in the microscope it is very small. If, in the latter, an object-glass be used of one-eighth of an inch focal distance, and the object be so placed that its image is formed at six inches, the image will be of diameter 48 times as great as the object, or will have nearly 2300 times as much surface; and if that image be viewed through an eye-glass of half an inch focus, it will appear still twelve times larger.

"*Rays of light falling on very smooth or polished flat surfaces are reflected so nearly in the order in which they fall, as to appear to the eye receiving them to come directly from objects originally emitting them. Such surfaces are called* MIRRORS; *the surface, which is flat as well as polished, is called a plane mirror.*" (Read the Analysis, page 498.)

1141. It is common knowledge that an elastic ball falling directly, or at right angles, on a level floor, rebounds directly upwards in the line in which it fell; but if it descend obliquely or slantingly from any side, that it will rebound just as obliquely on the other side. An illustrative experiment can be made with more precision on a level billiard-table, thus. Let M R mark part of the side of the table, and let a billiard-ball strike directly or perpendicularly the point C, from the position *p*, in the line *p* C, it will rebound in the same line from C to *p*. If the ball be then shot obliquely towards C, in the line A C, it will rebound just as obliquely from C to *a* on the opposite side of the perpendicular *p* C. The angle A C *p* is called the angle of approach or incidence, and the angle *p* C *a* is called the angle of return or of reflection (see the Mathe-



matical Appendix), and these two angles will always be equal to each other, whatever their size. This important law of equal angles of incidence and reflection holds in many other cases, as in the reflection of waves of water from a perpendicular wall, the reflection of sound from a flat echoing surface, and that which now concerns us, the reflection of light from the surface of a plane mirror.

1142. It follows from this that if the straight line M R be taken to represent part of a mirror seen edgeways, an eye placed at *p* would see itself as if it were directly beyond the part of the mirror C, and an eye at *a* would see any object really in the situation A, as if at P, beyond the point C in the line *a a'*, and similarly for all other positions and directions, the objects before a mirror appearing to eyes before it as if they were beyond it at their true distance, in a line passing perpendicularly through it. The object at A, for instance, would to an eye at *a* appear as if at *a'*. Where the existence of the mirror is not suspected, the objects in front reflected from it appear to be realities placed beyond it, in lines perpendicular to the surface of the mirror. A wild animal will attack its image in a glass; and the fable says that a dog crossing a brook quitted the piece of flesh in his mouth to catch the tempting image of another piece which he saw in the water below. The reason that an object seen in a plane mirror appears to be just as far beyond the mirror as it is distant on the side of the spectator, is, that the apparent diminution of size, the divergence of the rays of light from it, and the convergence of the optical axes looking at it, all correspond to that supposition.

Mirrors are often placed at the sides of shop-windows to make the store of merchandise displayed there appear greater than it really is.

Any plane very smooth surface reflects light more or less as now described, and is a mirror; but different substances send back very different proportions of the light which falls on them. A highly-polished metallic surface is the best mirror, often returning three-fourths of the whole light. Hence in reflecting telescopes, the mirror, there called a *speculum*, is made of polished metal.

1143. Our common looking-glasses are really metallic mirrors, for it is the smooth clear surface of the quicksilvered tin-foil behind the glass which reflects by far the greater part of the light, the glass itself serving the purpose of preserving the metallic surface perfectly clean and flat. There is always an imperfection in such glass mirrors, when used for viewing objects obliquely, because the external surface of the glass also acts as a mirror, although so much more feebly than the metal behind, and forms a separate image not quite coinciding with the other.

1144. The mirror-power of glass alone is seen in the panes of a plate-glass window, particularly where there is a dark background. In the shop-windows of London, passengers on the pavement are often seen studying their own reflected appearance, while appearing to be looking at the wares within. All ordinary sheets of glass, in windows or in picture-frames, reflect much light, but the reflection being irregular where the surface is irregular, the fact scarcely attracts notice.

1145. The smooth surface of a fluid is a mirror, and in ancient times was the only kind known. It is, moreover, horizontal. When that surface is metallic, as of mercury, the mirror is perfect. The mirror of liquid quicksilver is often used by astronomers in observing the apparent altitudes of the heavenly bodies. Because the image in the mirror appears exactly as much below the horizon as the object is really above it, half the distance between them marks the true horizontal level.

1146. A varnished picture is a mirror, and if placed so as to reflect strongly the light of a window or of the sky, it prevents spectators from seeing the subject of the picture. Even a polished table of mahogany, or other wood, is a mirror, as is well known among playful children. Polished stones, as marble slabs, &c., and smoothly-painted walls reflect considerably. Even a surface of air may act as a mirror, as where a cold and dense stratum happens to lie in contact with a warmer and rarer stratum. In such cases, where different levels of the atmosphere have become unequally heated, the trees, islands, etc., happening to be below, are reflected from above, and appear as if in the sky. This phenomenon is called *mirage*. It is often to be observed over the sandy deserts of Africa and elsewhere; certain kinds of mist and thin clouds produce a similar effect, causing, for instance, a ship to appear as if suspended aloft, with keel uppermost.

1147. Many persons do not observe that in looking at themselves in a mirror, the right side of the image shows the left side of the person. A blemish in the right eye of the spectator appears in the left of the image. A man presenting his right hand towards the image is met by a left hand from behind the glass. The effect is strikingly seen when a printed page is held up before a mirror.

1148. It is on this account that a careless artist, painting his own portrait from a mirror, may reverse all the peculiarities which are not the same on both sides; and if, as is often true, one eye is a little higher than the other, or the nose is not quite in the middle, a very incorrect resemblance will be produced. Hence, also, a person whose countenance is at all thus irregular, never sees himself in a mirror as he appears to others; and a belle or a beau, who has decided that a curl is more graceful on the left temple, may unconsciously leave it on the right.

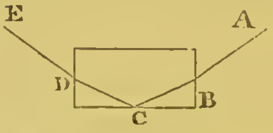
1149. By an image, however, which is reflected from a first mirror to a second, and from that to the eye, persons may see themselves, if they choose, as others see them. It were well if there existed moral mirrors to answer an analogous purpose!

1150. A candle placed between two parallel mirrors fixed on opposite sides of a room, makes visible in either glass to a spectator placed on one side an endless straight line of lights. If the glasses are inclined to each other, the lights will appear as if placed in the circumference of a circle, of which the centre is where the mirrors if prolonged would meet: this fact is well illustrated in the beautiful toy called the *kaleidoscope*. It is possible to place a few mirrors in such situations around an apartment, that a man entering it may see himself multiplied into a crowd, and a few ornamental pillars may appear endless colonnades,—as in the famed café *a mille colonnes* in Paris.

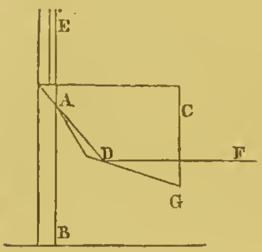
1151. There are few more amusing toys than two small mirrors, united like the boards of a thin book, with the leaves removed. This set up edgeways on a table, with some objects placed between the mirrors, when opened at different angles, affords endless amusement, illustrating the law of mirror reflections.

1152. The sun or moon reflected in a still lake, appear exactly as they do in the sky; but if the surface of the water is raised into waves by the wind, instead of one distinct image, there will be a long line of bright tremulous reflection; the reason of the appearance being, that every little wave, to a considerable distance, has some part of its rounded surface with the direction or obliquity which, according to the required relation of the angles of incidence and reflection, fits it to reflect the light to the eye, and hence every wave in that extent is sending its momentary gleam. Summer visitors from the interior of a country to a southern coast, as from London to Brighton, often express wonder at the great difference of climate, or the heat and light encountered when they walk along the cliffs, not reflecting that in the reflection from the sea they have almost a double sun.

1153. Although the external surface of glass reflects but a small part of the light which falls upon it—being therefore a feeble mirror, still, curiously, if light, which has entered a piece of glass, fall very obliquely upon the back or internal surface of it, instead of passing out there, it is more perfectly reflected than it would be by the best metallic mirror. Thus, light from A entering a piece of glass at B, is entirely reflected at C, on the internal back of the piece, and escapes at D towards E.



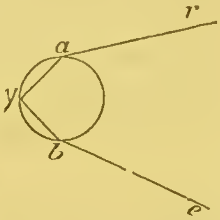
1154. It is this fact which enabled Dr. Wollaston to devise that beautiful little instrument called by him the *Camera Lucida*. The letters A G C indicate a piece of glass with a vertical surface C, and a horizontal surface between C and A. The light entering from an object or scene F, falls on the oblique surface D, from which it is reflected to the oblique surface A, from which it is reflected again to the eye at E, enabling that to see clearly the object at F. The wide pupil of the eye at E can also see past the corner of the glass at A, the sheet of paper on the table below it, B, and at the same time the objects at F, as if traced on the paper. With a lead-pencil that appearance can be made permanent, and a correctly-drawn outline of the scene is at once obtained. This instrument for assisting draughtsmen is still simpler than the camera obscura. Other modifications of it have since been contrived.

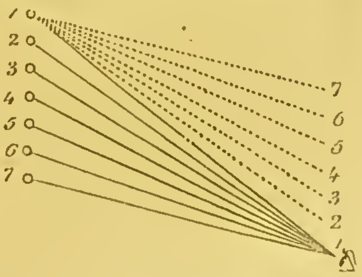


1155. The same fact of the internal surface of a transparent mass becoming a mirror, furnished at last the explanation of that apparition so admired before it was understood, and not less admired since, of the *rainbow*, or *arc in the heaven*, as in France and elsewhere it is named—an object which the poets of nature have seemed almost to worship for its beauty.

When a partial shower of rain falls on the side of a landscape opposite to that where the sun is shining, there appears in the shower this marvellous arch, red at its external border or confine, and then successively orange, yellow, green, &c. (in the order of the colours of the prismatic spectrum described in Art. 1031), towards its inner border. Its centre is directly opposite to the sun, or at the end of a straight line supposed to pass from the sun through the eye of the spectator to a point below the opposite horizon. The diameter of the circle of which the bow is a part, is of nearly 84° of the sphere of view. There is frequently seen also a second bow of much fainter light than the first, and with the colours in reverse order, of greater diameter, and therefore external to the other.

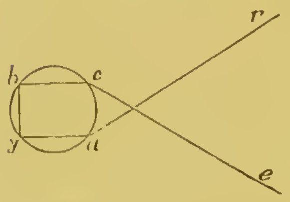
Now the explanation of this interesting phenomenon is as follows:—While the sun shines upon the spherical drops of falling rain, the light entering the whole central part of any drop, passes completely through, but that portion which enters obliquely near the edge of the drop, as at *a*, is refracted or bent, and much of it reaches the back surface of the drop at *y* so slantingly, or at such an angle, that it suffers there an entire reflection (Art. 1153), instead of being transmitted; the ray, therefore, is returned to *b*, where it escapes from the drop, and as here shown, descends to the earth or eye in the direction *b e*. Thus every drop of rain on which the sun shines is a little mirror suspended in the sky, and is returning at certain angles, a portion of the light which falls on it; and an eye placed in the required direction, receives that reflected light. If in this case, however, there were *reflection* only, and not also *refraction* with *separation of colours*, the rainbow would be only a very narrow resplendent arc of white light, formed by millions of little mirrors in the sun; but, in truth, because the light which enters near the edge of the drop traverses the surface very obliquely, it is much bent or refracted at *a* before its reflection at *y*, and at *b* after that, and is divided into rays of its seven colours, as it would be on passing through a prism (as explained in Art. 1031); and in consequence of this division or separation of the light, as it escapes from the drop at *b*, instead of one white ray descending from each drop to a certain point of the earth, seven rays descend (here marked by dotted lines from the figure 1 on the left hand, to 7, 6, 5, &c., on the right). The separation





in the drawing is made greater than occurs in reality to render the fact more evident. Of these coloured rays, an eye can only receive one at a time from the same drop, which drop will then appear of the colour of the ray; but for the same reason that seven eyes placed in a line from above downwards, as at 7, 6, 5, &c., on the right, would be required to see the seven colours from one drop in the bow, so one eye looking in the direction of seven drops situated in a corresponding row, as from 1 to 7 on the left, will catch the lower or red ray of the upper, the orange or second ray of the next, the yellow or third ray of that which follows, and so on, while it will lose all the others, and thus will see the several drops as if they were each of one colour only. Of such elements, then, found in the same relative directions all around the sky, the whole arch is formed. No two eyes, even of the same person, can see the same rainbow, that is, can receive light from the same drops at the same time; and the same eye does not for two instants receive light from the same drops.

We have here described what is called the principal bow, formed in the drops by two refractions, and one reflection of light. To produce the fainter second or external bow, mentioned above, and of which the colours are in reverse order, the light which enters on the under side of the drop, as at *a*, is reflected first at *y*, then again at *b*, and escapes at *c* towards the eye: after two reflections as well as two refractions. As the semidiameter of this bow is 108°, it may be visible when the internal bow is not.

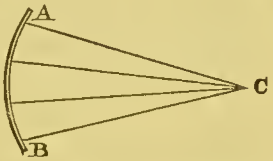


An artificial rainbow may be produced in sunshine at any time by scattering water into drops from a whirling brush or otherwise, on the side away from the sun at a moderate height; and a rainbow is often seen among the spray of a lofty waterfall, or of waves in a storm. The cut-glass ornaments of chandeliers, &c., produce colours on the same principle as rain-drops. Mist and particles of frozen water between a luminous body and the eye, produce the circular *halos* with little colour often observed around the sun and moon. A white *halo* is light reflected from the external surfaces of drops or solid particles.

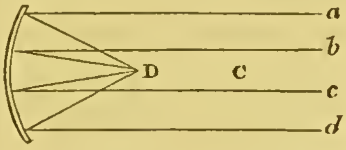
"*Mirrors may be plane, convex, or concave; and certain curvatures will produce images by reflection, just as lenses produce images by refraction; in consequence there are reflecting telescopes, microscopes, &c., as there are refracting instruments of the same names.*" (See the Analysis, page 498.)

1156. While a plane surface reflects light, so that what is called the image in it of a known object in front may readily be mistaken for the reality, convex or concave mirrors reflect as if every distinct point of them were a separate exceedingly small plane mirror, and their effects on light depend on the relative inclination of the different parts. The forms of importance are the regularly spherical and the parabolic concave, and convex mirrors. (See the Appendix.) These produce on light effects similar to those of lenses, only the concave mirror answers to the convex lens, and the convex mirror to the concave lens. It is the concave mirror, as a speculum, which gathers the light to form the images in the most powerful telescopes that exist, as those of Herschel, Lord Rosse, and others. Admirable as is the refracting telescope, it still falls short in certain respects of the telescope acting by reflection.

1157. In a hollow sphere, or part of a sphere with polished internal surface, if rays radiate from the centre in all directions, they reach every part perpendicularly, and therefore are thrown back to the centre (1141). Thus, if A B were part of a concave spherical mirror, of which C were the centre, rays issuing from C would, in obedience to the law, that "the angle of incidence and reflection are equal," again meet at C.

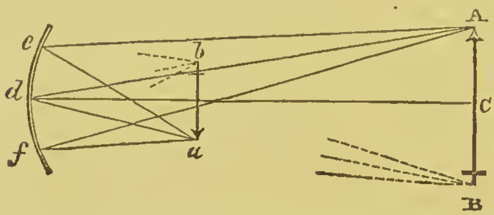


1158. It can be proved also, that any ray parallel to the axis of the mirror, falling upon such a mirror, will be reflected inwards so as to cut the axis half-way between the mirror and its centre, *viz.*, at D, the centre being C. Then, as all parallel rays must meet in the same point, that point becomes a focus, as already explained for lenses, and there, when the mirror is held towards the sun, an image of the sun will be formed, as in the focus of a lens. This point is called the principal focus of the mirror.

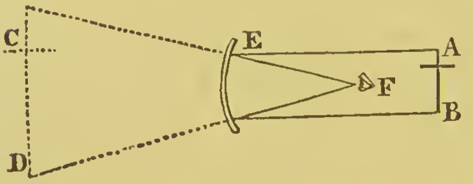


For the same reason that parallel rays, when reflected, meet in the focus, so will rays, issuing from the focus towards the mirror, become parallel, after reflection, as seen above or in the figure (Art. 875); and if they be then caught in a second and opposite mirror, as also represented at (875), corresponding effects will follow.

1159. Now, for a concave mirror, as already explained for a lens, in whatever direction a pencil or cone of rays may fall upon it, they are equally brought to a focus somewhere in the line of the central ray of the pencil, and when the rays fall on the mirror with a certain obliquity from one side of its axis, as here from A, the central ray of that being A *d*, and the axis of the mirror being C *d*, their focus will be with the same obliquity on the opposite side of the axis as here shown at *a*, in the direction *d a*, following the central ray in its reflection, and therefore the mirror will form an inverted image of any object placed before it, just as a lens does; and the image will be near or distant, and large or small, according to the divergence of the approaching rays, exactly as happens with lenses. Thus, the camera obscura, magic lantern, telescopes, and microscopes, may all be formed by mirrors, as they are formed by lenses. Moreover, concave mirrors magnify, and convex mirrors minify, as lenses of the opposite names do. The two subjects, therefore, of images by refraction and by reflection run so nearly parallel, that it would be useless repetition here to enter upon the detailed consideration of the latter, and we shall be content with showing, further, why a concave mirror magnifies, and why a convex mirror minifies.



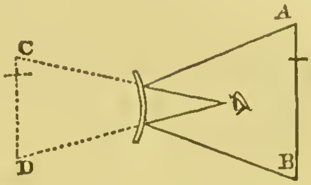
1160. A concave mirror magnifies because a ray of light nearly parallel to the axis of the mirror, passing from the top of the cross A, to the part of the mirror where it will be reflected to an eye placed near the focus F, seems to the eye to come from C, and the light from B similarly appears to come from D, so that the cross A B, by the reflection, seems to the eye to be of the greater dimensions C D.



1161. In a convex mirror, again, for corresponding reasons, the cross A B reflected appears only as C D, and therefore smaller than the reality.

Concave or magnifying mirrors, are often used by persons in shaving.

A convex mirror hanging from the ceiling, is a common ornament in apartments, exhibiting a pleasing miniature of the room and its contents.



1162. Any polished convex body is a mirror, and therefore the cornea of the human eye is one, in which persons may contemplate most perfect miniatures of a window or any bright object. It is the image of the window, or of the sun in the convex mirror of the eyeball, which painters usually represent by a spot of white paint there, sometimes without knowing what it represents; and a similar luminous spot or line must be made when they have to picture almost any of the pieces of furniture which have rounded polished surfaces, as bottles, glasses, smooth pillars, &c.

Convex lenses thus are also mirrors to all the objects around them, and very strikingly so, owing to the perfect form of a lens. The polished back of a watch, in the same way often attracts the attention of a child, who wonders to see there so clearly his own features.

It has been a mathematical amusement to calculate what kind of distortion mirrors of unusual forms must produce, and then to make distorted drawings, which when reflected from such mirrors, will produce in the eye the natural form of the objects.

1163. When a concave mirror is used for a telescope, the image formed in front of it, to be examined through the magnifying eye-glass, may be viewed in various ways,—first, as in *Herschel's* telescope, by the spectator turning his back to the real object, and looking in at the mouth of the telescopic tube, near to the edge of which the image is thrown by a slight inclination of the mirror at its bottom:—or, secondly, as in the *Newtonian* telescope, through an opening in the side of the tube after being reflected by a small plane mirror placed diagonally in the centre of the tube:—or, thirdly, as in the *Gregorian* telescope, through an opening cut in the centre of the principal mirror or speculum, after being reflected towards that opening by a smaller mirror placed in the centre of the tube with its face towards the observer: this last arrangement is that preferred for small telescopes, because the spectator, while seeing the image, is also looking in the direction of the object.

1164. Reflecting telescopes have the advantage of being perfectly *achromatic,* that is, of producing the images quite free from coloured or rainbow edges; for compound light is reflected, although not refracted, entire, all the colours following the one law of equal angles of incidence and reflection.

1165. Herschel's largest telescope had a mirror of 48 inches in diameter, and, therefore, to form images, collected about 150,000 times more light than can enter the pupil of an unassisted eye, forming, with that light, at a focal distance of 40 feet, a large image admirably distinct. It was with this telescope that, in the obscurity of remote space, Herschel discovered the immense planet rolling along, which in honour of his royal patron, he called the *Georgium Sidus,* but which now, by the decision of the scientific world, is called Uranus;—and with this he discovered moons, before unseen, of other planets, and he unravelled many of the celestial nebulæ and clustered stars of the milky way, and, in a word, unveiled, vastly more than had before been done, the system of the boundless universe. If this world, with men upon it, last for millions of years, the discoveries made through Herschel's telescope must mark a memorable epoch of its earlier history.

1166. Other steps of advancement have been made since Herschel's time. Lord Rosse has constructed a reflecting speculum nearly twice as large as Herschel's; and Mr. Foucault, of the French Institute, has laboured with admirable skill in forming good specula or mirrors of glass coated with metal. The expense of such is less than of merely metallic reflectors like those of Herschel, and it is hoped that difficulties which still attend them will be overcome.

"*Light reflected from, or traversing bodies of irregular surface and structure, or which have other peculiarities, is so modified as to produce all the phenomena of colour and varied brightness seen among natural bodies, giving them their distinctive characters and beauty.*" (See the Analysis, page 498.)

1167. General remarks on this part of our subject were made in the beginning of the section, in the explanations of how objects not self-luminous become visible by reflecting the light coming from other bodies, and of how the prism separates a ray of white light into rays of the several colours which are seen in the rainbow—which rays, on being again mixed, become white light as before:—and much beyond these remarks we have not the intention of now proceeding. To give an account of all that has been plausibly conjectured and said on the subject, would occupy the pages of a whole volume. There would be to pass in review the various opinions which have existed respecting the substance of light, the numerous facts connected with what is called the *polarisation* of light, the relation of light in its *double* or *multiple refraction*, to the ultimate structure of material masses, &c., Subjects all in certain respects very interesting; but, as some of them are not yet satisfactorily investigated, as respecting others, discordant opinions prevail, as they involve few matters yet bearing on practice, and as many of the reasonings concerning them rest on mathematical knowledge not yet made part of common education, they are held not to be for the present fit parts of a popular treatise on light. It is well to state, however, that persons who have the leisure, and the mathematical preparation necessary for pursuing the study, will have their labour richly rewarded.

1168. We shall only add here, that white light in falling upon any transparent substance, as air, water, or glass, formed into thin plates or films, is so affected, that for certain degrees of thinness, different for each substance, it is decomposed, and is reflected or is transmitted not as white light, but as some of the prismatic colours, and that the colour reflected in any case is the opposite or complement of that which is transmitted—that is to say, is such that the two brought together make nearly white light as before. Such facts may be studied, as Newton originally studied them, in the thin plate of air which occupies the space between a convex lens and a plane surface of glass upon which the lens rests,—in which plate, as the distance from the point at the centre or of the apparent contact of the glasses increases, there are all degrees of thinness, and with these appear successive rings of vivid colours. The same truth is exemplified, in the colours of a soap-bubble, which brighten as the bubble swells and becomes of thinner substance, and of different thickness from above downwards; and it is exemplified also in the colours seen in the fissures of cracked ice or crystalline spars, and in numerous other common facts. Whatever be the reasons of such decomposition or modifications of light—and the explanation is not yet complete—we cannot doubt that in natural bodies generally, the colours, opacity, transparency, &c., depend greatly upon the structure or arrangement of the minute particles, fibres or plates, with included interstices, which constitute the volume or structure of each mass. Accordingly, whatever changes these arrangements, may change also the colour of the mass. Thus, by drawing a certain number of very minute lines on a certain extent of any metallic surface, we may make it almost of what colour we please. Mother-of-pearl owes its vivid colours and beauty to its minutely furrowed or striated surface, as is proved by our taking an impression of that surface on sealing-wax, and perceiving that the wax then exhibits similar colours.

1169. In the meantime, the investigations in progress respecting the phenomena of light, are furnishing new proofs of the marvellous simplicity of nature, amidst the boundless extent and most curious variety. When men thought of the sense of touch, chiefly as produced by pressure on the tips of the fingers, or elsewhere on the skin, they were far from suspecting that the sense of hearing had the near relation to it which subsequent discoveries have proved, namely, that it is only a more soft or delicate pressure, made by undulations of the air or other substances on nerves protected within the cavity of the ear; and still less, did they suspect that the sense of sight was but a yet finer touch than hearing, produced by still more subtle vibrations of a medium of light on the interior nerves of the eye. But step by step they have ascertained the facts mentioned. And it is a curious resemblance that, while in sound, different tones or notes depend on the *number* of vibrations in a given time, so in light do different colours seem to depend on the *number* and *extent* of the vibrations of the more subtle medium, on which the phenomena of light depend. The human imagination cannot picture to itself a simplicity more fruitful of marvellous beauty and utility than all this! And yet farther, as air answers in the universe innumerable important purposes besides that of conveying sounds, so also does the medium of light minister in numerous ways, as in connection with the phenomena of heat, electricity, magnetism, and life.

The truths now posititively ascertained with respect to the nature of light and vision, are among those in the wide field of scientific inquiry, which, acting on ordinary mental susceptibility, place the student as it were in the very midst of the work of creation, awakening the most elevated thoughts of which the human mind is capable. Had there been no light in the universe, everything else in it had been, in regard to man, utterly valueless. In a word, he could not have existed. But the material of light does exist, pervading all space ; and impressions made on it in one place extend rapidly over the universe, in the progressive movement called rays or *beams of light*. These beams from all parts coming to every individual, may be regarded as millions of supplementary arms or feelers belonging to the individual, and making him almost everywhere present; then these members or feelers have no weight, they are never in the way, they impede nothing, and they are only known to exist when they can render service!

1170. But again this miracle of LIGHT would have been totally useless, had there not been the twin miracle of the EYE, an organ of corresponding delicacy, to perceive the light. In the *Eye*, is to be considered the round window called the cornea, of perfect transparency, placed exactly in the fore part of the precious globe (and elsewhere it had been useless); then exactly behind this, is the circular curtain, the iris, with its opening, called the pupil, dilating and contracting, without consciousness of the person, to suit the varying intensity of light; and exactly behind the iris, again, is the crystalline lens possessed of the remarkable power of bending the entering light, to form on the retina perfect pictures or images of all the objects in front;—the most sensible portion of the retina being just where the images fall. Of these parts and conditions, had any one been otherwise than just as it is, the whole eye had been useless, and light useless, and therefore the whole world useless to man. Then, further, we find that this wondrous organ is placed in the person, not as if by accident, anywhere, but aloft on a befitting eminence, where it becomes as the watch-tower of the soul; and, again, not so that to alter its direction the whole person must turn, but in the head, which on a pivot of very peculiar structure moves while the body is at rest; besides that, the ball of the eye itself, by its muscles, can turn in its adapted socket as the will directs, sweeping instantly round the horizon, or above the head across the whole heavenly concave; then is the delicate orb secured in a strong socket of bone, over which is placed the arched and padded eyebrow, to mitigate the shock of any accidental blow, and with its inclined hairs to turn aside any descending perspiration or other moisture which might incommode; then is there the soft and pliant eyelid with its beauteous fringes, incessantly wiping and moistening the polished surface, and spreading over it a pure moisture poured out from the lachrymal glands, of which moisture the superfluity, by a nice mechanism, is sent into the nostril, there to be evaporated by the current of the breath: still further, we have to note, that instead of there being only one so precious organ, there are two, lest one, by any accident, should be destroyed, but which two have so entire a sympathy, that they act together as one doubly powerful; and, finally, the sense of sight continues perfect from the birth of the individual to the maturity, although during growth a continual adjustment to one another of all the delicate parts has to be maintained; and the pure liquid which distends the eyeball, if rendered turbid by any accident, is by the actions of life, although its source be the thick red blood, gradually restored to purest transparency.

The mind which can suppose or admit that, by chance or without design, during any length of ages, one single such apparatus of vision, as above described, could have been produced, must surely want the higher faculties of reason which distinguish man from the lower animals.

As a concluding reflection with respect to vision, it may be remarked that all the provisions above considered have mere utility in view, as any one of them being absent would leave a necessary link in the complex chain wanting, and there would not be orderly method: but, we have shown in a preceding part of the work, that if there had been white light only, susceptible as now of different degrees of intensity and shade, the merely useful purposes of vision would have been answered nearly as well as with all the colours of the rainbow—a truth instanced in the facts, that some persons do not distinguish colours, and that it imports not whether a person view objects in the morning, or at mid-day, or at even-tide, or through plane glass or coloured glass, provided there be light and shade enough to show shape and position clearly. While, therefore, the existence of light generally, and of the eye, points to creative power and intelligence, the existence of colours, in the variety seen in flowers, in the plumage of birds, in the ever-varying aspects of the earth and heavens—because acting so directly, to give delight to animated beings, proclaims creative benevolence, and naturally awakens in human minds towards the Supreme Author of all, many of the feelings associated during this transient scene with the endearing name of father.

PART IV.

SECTION III. ON ELECTRICITY.

1171. As a preface to the account now to be given of what may be called the last great step in advance made by man in knowledge of the world around him, and of new useful purposes to be served, namely, knowledge of electricity, it is opportune to make a few remarks on *Man's Progress* generally as contrasted with the stationary condition of inferior beings.

There is clear evidence in history, and in still enduring results of human agency in very remote past time, that in all countries the population had long existed before acquiring the kinds of knowledge and arts which now distinguish civilized from savage men. And in many countries the steps can be distinctly traced by which, through the exercise of human intelligence, advances were made.

In Britain, for instance, as stated by Macaulay in his history, "the inhabitants, when first visited by the Tyrian mariners, were in condition little superior to the natives recently of the Sandwich Islands;" and when Julius Cæsar afterwards invaded the country little change had taken place. They dwelt in mud hovels among the trees of the uncleared forests. They scarcely practised tillage of the ground. Their bodies were scantily covered with the rough skins of animals, or paint. They were divided into tribes, often at war among themselves. Their religion was a wild superstition leading to human sacrifices.

Then, also, the people of ancient Greece, who afterwards became the most advanced on earth, once existed, according to their own historians, Herodotus and Thucydides, nearly in the condition of the early Britons as above described. They formed numerous small tribes, occupying not very fixedly different districts or islands, and treating one another much as in later times pirates have treated those whom they assailed. They would land on any coast supposed to be ill-defended, to seize the food or other property to be found there, slaying the men who resisted, and carrying away women and children to be slaves. They gloried in successful piracy. Domestic service among them, and the labour required in the rude arts then known among them, were performed chiefly by individuals of other tribes who had been made captives in war.

1172. These rude Greeks, however, living in a region and climate singularly favourable to the development of the high endowments of mind and body possessed by man, gradually changed their modes of action, and within a few centuries carried all the sciences and arts of civilization then known, to degrees of advancement far surpassing what existed elsewhere. Some of their wise men or philosophers, as Thales and Pythagoras, often at personal risk, travelled to the then more civilized countries, as Egypt and the East, to gather any knowledge which these could impart, and returning home they secured possession of what they had learned, by recording all in writings in their own beautiful language. And in every department they themselves soon added largely to the existing stock. Many of these Greek books remain to the present time—the admiration of the most cultivated minds in all countries. The names of Homer, Thucydides, Demosthenes, Aristotle, Euclid, Archimedes, among others, have not been eclipsed by any which have attracted notice in later time. In the solid works of architecture and sculpture, some of the very objects formed by the hands of contemporaries of the sages above enumerated are still in existence, serving as lessons to men of the present day.

Surprise has been expressed that, with the high powers of intellect possessed by man, the progress towards much of the knowledge and art now existing should have been so slow. One of the great impediments has been that wars have very constantly raged between the nations of the earth, originating in the ignorance of the masses, and the low animal passions, little controlled by reason, of the individuals raised to authority. Thereby free intercourse, with interchange of knowledge, was prevented, and, generally, the most gifted individuals have had their energies altogether absorbed in the contentions of war instead of in the pursuit of means tending to increase human happiness.

1173. It illustrates how wars interfere with human progress, to recall the fact that notwithstanding the rare mental abilities displayed by the Greeks, they could not defend themselves against the military strength of the Romans—a nation of warriors seeking the universal dominion which they ultimately achieved. The Greeks, when subdued by the Romans, in losing their freedom, were drawn from their nobler pursuits. The conquerors adopted much of the science and literature of the Greeks, but continued to follow their career of ambition. They sank at last under the despotism of military chiefs or emperors, and being then ruled by a single will instead of by the united wisdom of a senate, vices and misgovernment gradually crept in among them and undermined the national power. They were overwhelmed in the end by warlike nations of unlettered barbarians from the north and east,—Goths, Vandals, Northmen, &c. In its fall, their empire was divided into portions which have become the separate kingdoms of modern Europe. The invaders, although rude and ignorant, were brave, and many had high natural endowments. After the dismemberment of the empire, ages followed, during which little new addition was made to science, and not a little of old science was lost. The new feudal chiefs, and their followers, cared little at first for science or literature; or rather despised these as not being connected with martial glory, and the people generally almost ceased to read.

In the meantime, however, a benign influence was operating of the new religion, preached in Judea, which included the precepts, "Do as you would be done unto," "Love one another;" in other words, which inculcated universal justice and charity. The condition of the world has since then been gradually changing in accordance with these divine precepts. All civilized nations now adopt the words, but general practice is yet far from obeying the rules.

When a more tranquil state of the European mind had arisen, individuals of high mental power began to work well, as of old in Greece, and the writings of the ancient Greeks were again studied. Valuable new discoveries in science and art were made, and improvements on old discoveries of equal importance with the new. Among these were the invention of gunpowder, of the art of printing, and of the mariner's compass, and many others.

1174. In the year 1480 the conviction came to the noble Columbus, that this earth was not, as was generally believed and asserted by the highest authorities, an extended surface nearly level, but a ball or globe on which, all round, the inhabitants were distributed, and that a ship could reach the East Indies by sailing westward, as certainly as by rounding the Cape of Good Hope to the east. The first voyage planned by him proved the soundness of his views; but he found lying in his way a new hemisphere, or half of the world, now called America, until that time quite unknown to Europeans. Then came the proofs gathered and arranged by Copernicus the Danish monk, and Galileo the Italian professor, that this earth was not, as asserted by the authorities of the time, the fixed centre of the universe, round which the sun and stars were revolving, but one of a number of planets, some larger, some smaller than it, revolving about the sun as a centre. Galileo was the inventor also of the telescope and of the pendulum, which now measures time. His pupil, Torricelli, invented the mercurial barometer. Then came the most comprehensive discovery of all, by Sir Isaac Newton, of the law of universal gravitation. Gradually afterwards it was discovered by chemical processes, that all the bodies in nature, solid, liquid, or aëriform, consist of a few simple elementary substances variously combined. Such was the kind of progress.

1175. In the course of the last century many important discoveries had been made; and it was commonly said that during that one century a greater advance had taken place than during several centuries before. And showing a rapidity of progress still greater since then, young readers will be surprised to learn that when many of the persons now living were born, there was not in the world,

A railway,
A gaslight,
A marine steam-engine,
An iron ship, or house, or bridge,
Photographic views or pictures,
The penny postage,
The electric telegraph,
&c.

Were the world now to lose these again, or even any one of them, many persons would deem the change a relapse towards barbarism. The inventors of the two last-named novelties, Sir Rowland Hill and Professor Wheatstone, still living among us, were members of a small society of friends who met periodically at each other's houses to converse on matters of general interest,—of which society the writer had the pleasure to be one.

We proceed in this section to state what is now known of electricity and the uses made of it. When treating in paragraph (1173) of the obligations which the world owed to the ancient Greeks, the reflection offered itself, how incredible it would have appeared, even to the far-seeing Greeks, that the highest attribute which the popular imagination then assigned to Jupiter, the father of their gods, namely, that he held in his grasp the obedient lightning, would in future time be possessed by any person desiring it! Yet, truly, the matter of lightning lies concealed in every common substance, in the ground, the rocks, the water, and can be called into activity by simple artificial means which any student may learn to use; and the lightning so aroused may be, and is, employed as the common carrier of information and messages, conveyed with lightning-speed between the most distant parts of the earth—through the ocean as over the land; and further, men are now able to produce by it, anywhere, heat more intense than that of the fiercest furnace, light as brilliant almost as that of the sun, and chemical power strong enough to break up the most resisting unions.

Analysis of the Section on ELECTRICITY.

THE phenomena called electrical are nearly all explained by supposing that there exists—

1. *A very subtle elastic fluid diffused through all nature,*
2. *Having no weight nor inertia.*
3. *Being self-repellent, like compressed air or gas;*
4. *But strongly attractive of other things,*
5. *Which in its usual tranquil state of diffusion and equilibrium is unperceived by any of the human senses, but when disturbed can affect them all.*
6. *Its equilibrium is disturbed by various means, as by friction between two bodies of different kinds. This occasions a redundancy in one and a deficiency in the other, the one seeming to gain what the other loses. The first is said to be positively electrified, the other negatively.*
7. *Electricity acting to regain its equilibrium passes readily through some substances, as the metals, the earth, water, &c., which are therefore called conductors, and it is impeded or arrested by other substances, as by glass, silk, air, &c., which are therefore called non-conductors.*
8. *While regaining lost equilibrium, it occasions apparent attractions*

and repulsions among the ponderable bodies in which it is lodged. Bodies similarly electrified, whether positively or negatively, repel each other. Bodies dissimilarly electrified attract.

9. *Electricity can force its way through a moderate thickness of non-conducting substances, as air, glass, &c., appearing then as a vivid spark and causing a sharp snap or noise.*
10. *A body entirely surrounded, and therefore supported, by non-conducting substances, is said to be insulated, and may long retain an electrified condition.*
11. *A much greater charge of electricity can be accumulated on one side of a non-conducting substance, as a pane of glass or the interior of a Leyden phial, than if diffused over a larger mass of a conducting substance.*
12. *When electricity is produced by the mere contact of different substances peculiarly arranged, as in the voltaic pile or battery, it is said to form currents; these manifest remarkable powers, as in chemical decompositions, the electric telegraph, &c.*

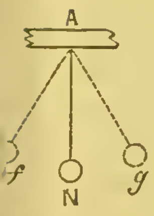
A second conjecture or theory respecting the nature of electricity is, that there are two electric fluids, each being self-repellent, but strongly attracting the other; the two being neuter when in due degree united, but active when separated. This supposition, however, little accords with the magnificent simplicity of general nature, and many minds remain in suspense regarding it. In fact, neither theory explains all the phenomena, but either aids the student's memory, by classifying the facts according to resemblances.

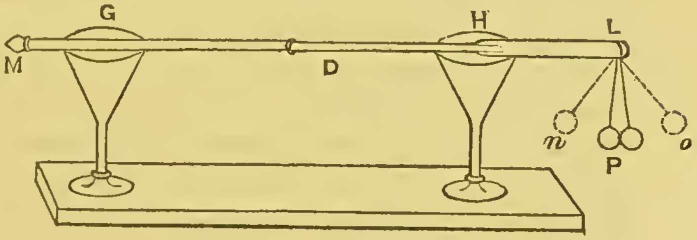
1176. When students open a treatise on electricity, and find in the first page the avowal that the ultimate cause or agent is not yet fully known, they may fear difficulty in comprehending a subject on which professed electricians do not agree; but they will become aware that complete knowledge is not essential, provided they have ascertained laws of the agency, so as to be able to command results. They may reflect that we have not yet discovered the cause of gravitation, but that the illustrious Newton, by detecting the laws of its action, increased most remarkably men's knowledge of astronomy, and advanced many of the most useful arts, as those of navigation, the constructing of time-keepers, &c. Then, further, we do not yet know completely the nature of heat; but James Watt, by discovering certain laws of its action, was led to the construction of his noble steam-engine, which has remarkably elevated the condition of men upon earth. Neither do we know fully the nature of light, but we have learned laws of its motions, which give us spectacles, telescopes, microscopes, &c. And so, although men may speculate differently with respect to electric fluids, they have learned enough of the laws to be able to defend their edifices, ships, and property generally, as well as their lives, from the destructive thunderbolt, by placing judiciously lightning conductors to carry the fluid safely to the earth ; and they have now at command that wonder of recent times, the electric telegraph. The nearest approach to knowing well some hidden thing, is to be told to what other known object it bears a close resemblance. In this view, we have spoken of electricity in the analysis above offered.

Apparatus.

1177. It is interesting to know how few the simple objects are which form an apparatus sufficient to exhibit the fundamental facts or truths of electricity, and that these are at hand in every ordinary dwelling-house. A person aware of this, and not choosing to make the easy experiments, would show singular disregard of important natural knowledge. The requisites are—

1. A silk handkerchief or piece of woollen cloth.
2. A piece of glass-tube, as Fig. B, or a long narrow phial. Some wine-glasses, G H.
3. Small round pieces of cork or balls of alder-pith, as Fig. N, hanging from any support by threads of white silk.
4. A stick of sealing-wax, C.
5. A common fire-poker, or any rod of metal, D.





Experiments.

1178 (*a*). If a glass tube B, or the bottom of a wine-glass, be rubbed briskly with a silk handkerchief made dry and warm, and if it be then held towards the cork ball Fig. N, hanging from the support A by a thread of white sewing silk, the ball will be drawn or attracted from the position A N to that of A *g*, nearer to the glass, and there it will remain while the position and electrical state of the glass continue. If the glass be moved about, the ball will move to follow it. (Analysis No. 8.)

(*b*). If then the electrified glass and ball are allowed to touch each other, the ball receiving part of the electricity would instantly dart away or be repelled by the glass; and if the glass be moved towards it from any side, it will elude the approach, like a living thing terrified. (Analysis No. 8.)

(*c*). After the contact of the glass and ball, the ball will have acquired the power of attracting any other light thing placed near it, as a second ball like itself, and if these be allowed to touch, they will instantly repel mutually, as the glass and ball did in the last experiment.

(*d*). A glass tube being a non-conductor of electricity, if held by one end, loses its charge only slowly, and chiefly to the air; but if a hand be passed along its surface, the hand, being a conductor, carries away the electricity, and the natural or normal state of the tube is restored. (See No. 7.) So an electrified cork ball, which attracts and is attracted by things around, if allowed to touch a finger, loses its electricity and comes to rest in the natural position of the pendulum.

(*e*). If, instead of one ball hanging from the support, there are two, and in contact as at point L, on touching them with the electrified glass, they dart asunder, and if the glass be placed between them, they separate still further.

(*f*). If a metallic rod D, as a common fire-poker or a length of thick wire, which are conductors, have attached to it, at one end L, two pith-balls hanging by fine wire or linen thread, and if the rod be insulated by being supported on two wine-glasses G and H, as shown above, and if then the end of the rod M be touched by the excited glass-tube, the two balls at the end L will instantly repel each other as if the glass had touched them directly, showing that the metallic rod gives instant passage to the electricity from the glass to the balls. The rod or wire might be of great length, and still the effect would be produced.

(*g*). If the electricity be strongly excited on a large glass-tube in the dark, the surface is often slightly luminous, and minute sparks are seen to pass from the glass to knuckles held near, and a slight crackling noise is heard, showing that all our senses can perceive excited electricity.

(*h*). The set of experiments described above may be performed more feebly by using the silk with which the glass had been rubbed, as the electrifier, instead of the glass itself, but with this singular difference, that the bodies which are attracted by the glass are repelled by the silk, and *vice versâ*. One of the rubbing bodies seems to gain what the other loses.

(*i*). There is the same remarkable opposition, if, instead of using glass and silk to evolve the electricity, a stick of sealing-wax and silk or woollen cloth are employed. The electricity from the sealing-wax is of the contrary nature to that from the glass, and of the same nature as that from the silk which has rubbed the glass.

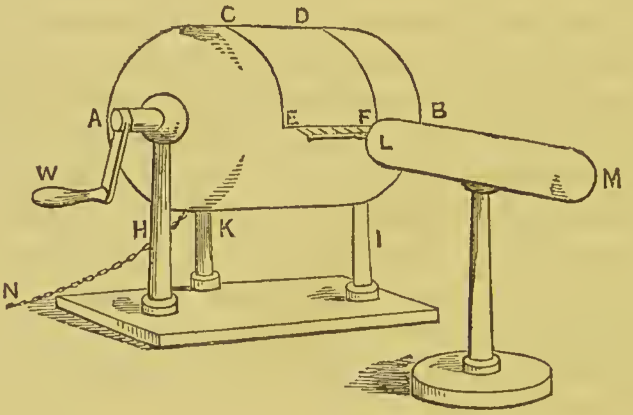
1179. These results at first suggest that there may be two distinct and opposite kinds of electric fluid, the *vitreous* and the *resinous;* and many inquirers have so conjectured. Others, of whom Franklin was one, have thought that the difference is only in the quantity or condition of the agent, as boiling and freezing water differ only in the amount of heat in them; or as a heavy stone and a light balloon have not two opposite qualities of gravity and levity, but differences in the common quality of weight. (See the analysis No. 6.) If the surface of a glass tube be roughened before being rubbed, it produces the negative or so-called resinous electricity instead of the positive or vitreous. It matters little what theoretical view be taken provided the important facts are recalled.

The earliest recorded observation of an electrical phenomenon we owe to Thales, the Greek philosopher, who lived 2,500 years ago. He saw that *amber* (in Greek called *elektron*) when rubbed on woollen cloth first attracted small light bodies, and then, if allowed to touch, immediately repelled them. Little more was noticed until about the beginning of the last century, when Dr. Gilbert, an English physician, published a meritorious work on magnetism and kindred phenomena. Dr. Franklin, in North America in the year 1752, proved the identity of electricity and the lightning of the thunder-storm; and it is since then that the great discoveries and applications to useful purposes have been made.

The Electrical Machine.

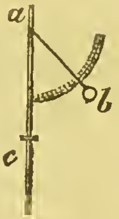
1180. When persons had become familiar with the simple experiments described after Art. 1177, they naturally concluded that with larger apparatus of the nature sketched there, the facts might be exhibited on a grander scale, and that probably new facts of importance would be discovered. The result of many devices and trials was the construction of what is now called the electrical machine of friction, now to be described.

The essentials of the simple apparatus sketched in page 607 are three: the glass to be rubbed (the tube), the silk with which to rub (the handkerchief), and the objects to receive the electricity (the cork, pith-balls, or poker). Then, 1st, in lieu of the tube has been substituted the large glass cylinder here represented A B, about 20 inches long and half as wide, to be turned like a grindstone or barrel-organ by a winch-handle, W. It is insulated by being supported on non-conducting substance, namely, glass pillars H and I. Secondly, instead of the loose handkerchief for rubbing, there is used a flap or breadth of silk cloth laid on the upper part of the cylinder, of which flap half is here seen, C D E F, on the side towards the spectator, the other half being behind, with its horizontal edge or border fixed on a cross piece of wood, also supported on a glass pillar K. This cross piece has a soft covering, rendering it a cushion which bears gently against the cylinder, and becomes the solid part of the rubber. Thirdly,—Instead of the cork or elder balls to receive the electricity, there is the large cylinder with rounded ends, L M, made of plate-metal also having a glass



support. This cylinder is called the *prime conductor*, and when in its place, its extremity L with metallic points projecting to receive the electricity, is brought close to the loose border of the silk E F.

When the cylinder is turning, the electricity is evolved between the rubbing silk and the glass surface, and is carried forward to be delivered to the metallic points on the prime conductor L M, where the silk terminates. There is a metallic chain attached to the cushion of the silk rubber, and hanging down to the ground at N, by which the electric fluid ascends from the earth as the machine works. On some part of the prime conductor, as at M, is placed a small electrometer-pendulum, consisting of a pith-ball, *b*, hanging by a slender arm, *a b*, from the top of an upright stalk, *a c*, and which, by the distance to which the pith-ball is repelled from the stalk tells the intensity of the electric charge or accumulation in the prime conductor. A similar electrometer placed on the rubber-cushion behind, when the supplying chain, N, is removed, tells the degree in which the rubber-cushion or anything connected with it is negatively electrified.

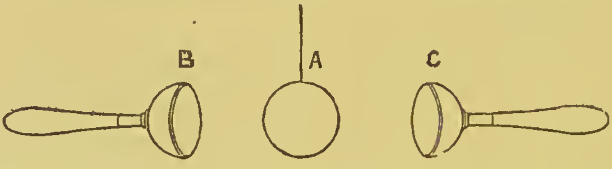


There are two other forms of electrical machine in common use. Of these one is called the *plate machine*, having a circular plate of glass turning on its axle, instead of the cylinder shown above, and the supports, rubbing silk, and conductor are formed and arranged to suit it. The other, called the *hydro-electric machine*, is simply a small boiler for water, insulated on glass supports, with the fire or fuel box within it; and the exciting friction is produced by the high-pressure steam, with small globules of water, rubbing forcibly against the sides of the irregular passage through which it escapes to the atmosphere.

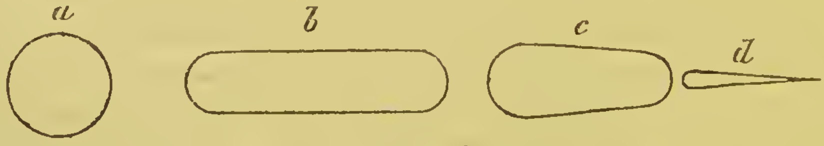
When a large electrical machine, like any one of those above described, is employed, instead of the diminutive apparatus sketched in Art. 1177, there are the following differences. The faint luminosity on the simple tube is converted into vivid sparks constituting almost a cascade of fire passing from the loose end of the rubbing silk to the prime conductor, and at short intervals a decided flash with loud crack darts from the conductor to any object placed near it. If a bystander approach his hand he receives the spark or flash with a painful prick and even with momentary numbness along the arm. A person insulated by standing on a stool with glass feet, if he touch the conductor, becomes so strongly electrified as to give out sparks from the fingers to a person wishing to shake hands with him. These sparks are strong enough to light a gas lamp or to explode a fulminating powder.

1181. When the equable distribution of electricity in bodies is disturbed by friction or otherwise, causing redundancy in one body and deficiency in another, the self-repulsion where there is redundancy causes the fluid to pass instantly from where it is in excess, through any conducting substance which offers, either to the earth, which is the general reservoir, or still more readily to a body in a negative state; and where no conducting medium is very near, the fluid will force its way or burst through a short length or thickness of a non-conducting substance, such as air, in the form of a brilliant spark.

1182. By the use of the large machines other important facts were soon strikingly demonstrated. Thus, owing to the self-repellent nature of the electric fluid, when it is thrown in excess on any conducting body, it diffuses itself not through the whole mass, but over the surface only. If the body be a sphere or ball (A) suspended by a silken cord and highly electrified, and if there be two metallic cups, B and C, which exactly cover or fit the sphere, if the cups, having handles of glass, be applied closely to the ball, and then removed, the whole charge of electricity is found to have passed to the cups, leaving the ball in a perfectly natural or normal state.

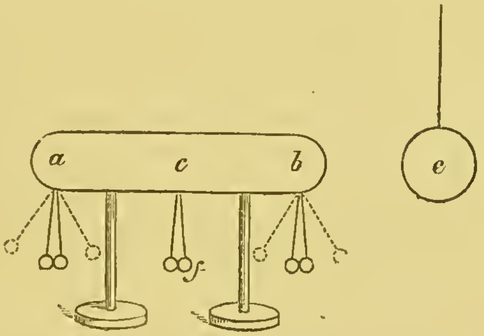


1183. Owing to the same self-repellent nature of the electricity, when a charge is thrown on any body, it does not spread or distribute itself uniformly over the body unless the form be that of a perfect sphere or ball as *a*. If the body be oblong, as *b*, the repulsion of the fluid in the central parts increases the density of it towards the ends. Then, if one end be smaller



than the other, as in *c*, the density is greatest at the small end And if the extremity be a point, as in *d*, the density becomes there so great that the fluid is forced into the air, and, gradually electrifying the air in contact, passes away. The flame of a candle held near an electrified point appears to be blown away from it. For the same reason that positively electrified points quickly dissipate positive electricity, so do points in a negatively electrified body readily receive it. This is seen in the action of the points placed between the receiver or conductor of an electrical machine and the cylinder. And the fact is turned to account by giving to common lightning-rods sharp points directed to the sky.

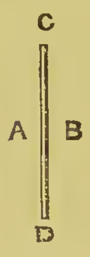
1184. The self-repulsion of electric matter is strikingly illustrated in the following experiment, which is said to exhibit its "influence at a distance," or when acting by *induction*. Let *a b* be an insulated conductor, resting on glass supports, having pairs of pith-balls hanging by linen threads or fine wires from the ends *a b* and the middle *c*. When not electrified all the balls hang in contact, but if a positively electrified sphere, *e*, be brought into the position here shown, near to the conductor, yet not touching it, the two balls at *a* and *b* will instantly repel and fly apart as here shown by the dotted lines, those at *b* becoming negatively electrified, owing to the natural electricity of the conductor being driven towards the end *a* by the repulsion of the positive electricity in the ball *e*, and those at *a* becoming positively electrified, because the natural electricity of the end *b* of the cylinder is driven to *a*, making a positive charge there. No effect is produced on balls at *c* half way between the ends, because the quantity of electricity there remains the same. If the sphere *c* be withdrawn, all the repulsions described immediately cease.



1185. If during the last experiment, while the electrified body *e* is held near the conductor *a b*, causing the disturbance of the electric pendulums above described, a finger be applied for a moment to the conductor at *a*, allowing the positive electricity accumulated there to escape towards the earth, the pendulums immediately collapse. If after this the electrified ball *e* be carried away, the electrometers at *a* and *b* immediately diverge again, for the conductor by the touch of the finger lost part of its natural electricity, and remains altogether in a negative state. If then a finger approach the conductor it gives a spark, which restores what was taken away when the charged ball was present. This operation may be repeated many times by bringing back the same charged ball, *e*, at every repetition. If the ball could be long preserved without losing its positive charge, it would give the power of producing at will for the whole time sparks of considerable force. This principle will be referred to in the description of the *electrophorus* in Art. 1194, the nature of which it explains.

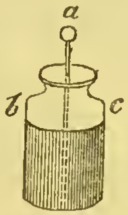
1186. It is a remarkable fact, that if a pane of glass be held between the ball *e* and the conductor *a b*, or in the experiments described after Art. 1177, between the glass tube or sealing-wax and the pith-balls, the attractions and repulsions still occur as if the pane were not there. The glass, therefore, although as a non-conductor it prevents altogether the passage through it of electricity itself, does not lessen that influence at a distance which is called its *power of induction.*

1187. This fact is still more strikingly illustrated when the attempt is made to charge with positive electricity one side A of a pane of glass (here represented edgewise by the double lines C D). The natural electricity of the side of the glass B resists or repels so powerfully the lodgement of the new electricity on the side A, that only a small portion can be there deposited; but if any conducting medium be interposed between the side B and the ground to allow the natural electricity from B to escape, a much greater new charge can be thrown on the side A, than can be given to an equal weight or extent of surface of even any conducting material—a plate of metal, for instance. This very important fact was discovered by accident in the year 1748, to the great surprise of those who witnessed it, and of students generally.

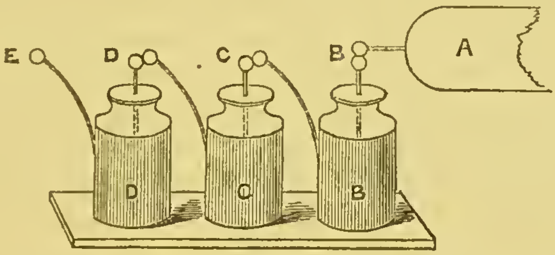


1188. An experimenter at Leyden, in Holland, with a view to ascertain the effect of electrifying water, placed in a phial containing water a short brass rod, and then held the end of the rod in contact with the charged conductor of an electrical machine. Having charged the water fully, as he supposed, he removed it from the contact, and then applying the other hand to withdraw the wire from the phial, he instantly received a violent shock through his arms and body, which caused him to drop the phial, and himself to sink benumbed to the floor. He believed that he had narrowly escaped death; and he afterwards said, that he would not take another such shock if the empire of Germany were offered as the bribe.

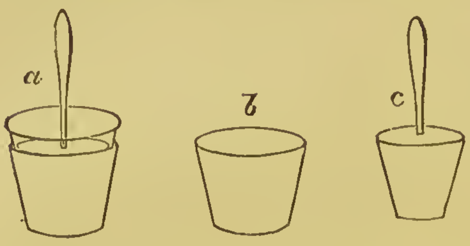
It was soon discovered, however that the charge was not in the water, but connected with the surfaces of the glass, the water serving merely as the conducting medium which joined together in action the several parts of the internal surface of the non-conducting glass; for the same effect was produced by substituting for the water a leaf of tinfoil, which could similarly cover the surface of the glass. And if both the internal and external surfaces of a bottle or jar were covered with tinfoil to within a short distance of the top, the jar could then receive a very powerful charge indeed. The adjoining figure shows a common form of jar so covered, and called the *Leyden Jar*. A brass rod with a nob at its top passes through a wooden stopper into the jar, and has a piece of chain hanging from its bottom in contact with the metallic lining, to establish communication.



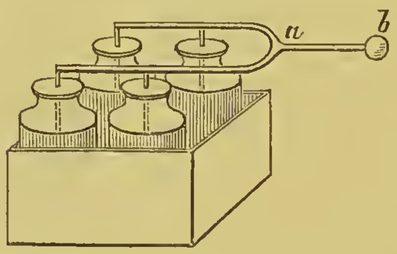
Owing to the strict relation between the electrical states of the two sides of a moderate thickness of glass, or other non-conductor of electricity, it is found that if a Leyden jar resting on a support of glass be charged by distinct sparks from a prime conductor—as the jar B from the conductor A—then for every spark which enters it a corresponding spark is driven from the outside to any conductor placed near, as C for instance, which is another jar, and if a row or series of such insulated jars stand as here represented, the charging of the first one B will charge all the others to the same degree.



1189. Further illustrating the views taken here, it was soon discovered that if a common glass tumbler *a* be set into a metallic vessel *b*, which exactly fits and covers the lower part of its external surface, and if it then receive into itself a smaller tin vessel *c*, with a handle of glass which closely fits the internal surface, the combination of the three, *a*, may be strongly electrified and discharged like a coated Leyden jar; but if after being electrified the smaller tin cover is lifted out by its glass handle, and the external tin cover is allowed to fall off, these tins are found to be in a natural state, and the whole electrical charge remains on the surfaces of the glass. The charge so left can be made to produce its usual effects by replacing the tins.

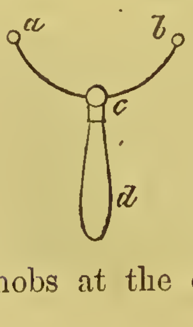


1190. The discovery of the nature of the Leyden jar gave an increased power of accumulating electricity, which changed the character of electrical proceedings. By connecting the interiors of many jars, and also the exteriors, to cause them to act like one larger jar, as here represented, effects are producible equivalent to those of the natural lightning of thunder. This combination is possible to any extent, and is called an *Electric Battery*.



To measure amounts of electricity and of the forces of attraction or repulsion exerted by them, a convenient means is the so-called *proof-plane* of Coulomb. A small disk of metal attached to an insulating handle of gum-lac is caused to touch an electrified body so as to share its charge, and being then presented to a body suspended from a torsion-balance, the extent of twisting produced indicates the force acting.

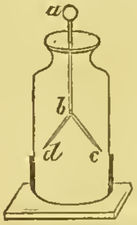
1191. The adjoining cut represents what is called a *general discharger*, by means of which an experimenter can, without danger to himself, send the charge of the most powerful battery through any substance exposed in its way. There are two branches, *a c* and *b c*, hinged together like the legs of a pair of tongs, with nobs at the enbs, and with a glass handle *d*. If one nob be



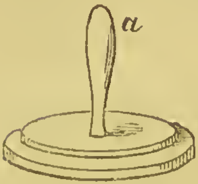
placed in contact with a conductor which communicates with either the external or internal surface of a battery, and if the other nob is then made to touch some conducting substance which leads to the other surface, the discharge instantly takes place, and electrical equilibrium is restored.

1192. Dr. Franklin was the first who thought of establishing a communication between an electrified cloud and the earth through the string, containing a fine wire, of a paper-kite sent aloft in thundery weather. He found that he could thus charge a Leyden jar, and so carry into his laboratory a part of the lightning with which to experiment as he might do with that given by an electrical machine. It was then that the precious thought occurred to him of setting up over roofs rods of metal with points directed to the sky, and the lower part piercing the earth, as certain means of safety, both on land and at sea, for property and life against the dangers of the thunderstorm.

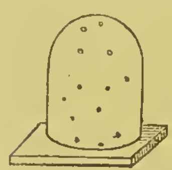
1193. A very sensitive electroscope or detector of electricity, is here sketched, which acts at once by induction. Its essential parts are the brass rod *a b* with a nob at the top and two strips of gold leaf hanging from the bottom *b*, within a glass shade preventing disturbance from wind. When there is no free electricity near, the leaves hang in contact, but with the slightest electrical charge, whether positive or negative, they stand asunder towards *c* and *d*, and more or less, according to the strength of the charge. If any electrified body approach the ball *a*, it acts by induction and throws the ball *a* into the contrary electric state to its own as explained in Art. 1184, and the induced charge in *a* produces the opposite charge in the leaves below, which therefore mutually repel. A piece of glass-tube rubbed by silk, if made to approach *a*, causes the leaves to separate because of its positive electricity, and when it is removed, the leaves collapse; but if the glass be allowed to touch the ball, the separation of the leaves remains after the tube is taken away, for a positive charge has been given. A stick of excited sealing-wax then brought near, causes first, collapse of the leaves, and if allowed to touch, produces the continued separation by negative electricity. The kind of electricity with which the leaves may be charged is thus discovered at once by approaching to the ball either a rod of glass or one of sealing-wax, excited by rubbing.



1194. The *Electrophorus* (electric carrier) is a simple arrangement by which a charge of electricity can be preserved for a long time in a condition which allows other charges to be produced by it through induction. It is thus formed. A mixture of shell-lac, rosin and turpentine, melted together, is poured into a mould of metal of the breadth of a dinner-plate, and becomes when cooled, a solid cake about half an inch thick. Upon the surface of this cake, resting on a table, is placed a metallic disc or plate smaller than itself, having a glass handle *a*, by which it can be lifted away from the cake. To prepare for use, the cake is struck briskly a few times with a cat's skin, and thereby is rendered highly electric negatively. The insulated plate being then placed upon it has, by induction, its under surface rendered strongly positive and its upper surface, therefore, negative. If while in this state a finger touch the upper surface, positive electricity is given to restore equilibrium there. When afterwards the plate is lifted away from the cake by its glass handle, the electricity lately given by the touch becomes a redundancy, of free positive electricity, which will pass as a spark to any conducting body which it approaches, and the spark is strong enough to light a gas-jet, or to effect other such purpose. This operation may be repeated any number of times for days or even months, without there being necessity to renew the friction with the cat's skin.



1195. An amusing and instructive experiment is, to electrify the interior of a drinking goblet by letting a pointed metallic rod projecting from a charged conductor touch in succession many parts of the internal surface while the hand is touching corresponding parts of the exterior. If the electrified goblet be then inverted over some pith-balls laid on a table, these will begin to dance or leap up from the table to the electrified parts of the glass, and taking there a charge of electricity, will dart down again to re-ascend until the electric equilibrium is fully restored. By placing the hand on different parts of the exterior of the glass, the motions are much quickened, because the hand supplies the electricity needed at the points opposite to where the balls strike.



1196. One of the most remarkable facts connected with the electrical discharge is the almost inconceivable rapidity with which the influence passes from one body or place to another. It equals that of light, exceeding thousands of miles in one second, during which a walking person makes a single step. We shall have to consider this again, under the head of the Electric Telegraph.

If a conducting wire, or a strip of metallic foil adhering to the surface of glass have divisions or small open gaps made in it, the electricity darting across the interruptions becomes visible at every one as a bright spark. Thus luminous letters or writing, consisting of lines of dots of light, are producible at each single electrical discharge.

1197. The charge of a battery when passing through air, appears as a flash, with brilliancy proportioned to the amount of the charge. It can heat to melting, and even to dissipation into vapour, wires or thin leaves of any metal. It can set fire to combustibles. It pierces resisting bodies standing in its way, leaving an open passage through them. It can destroy the magnetism of a compass needle. It decomposes chemical unions into their elements, as when separating water into the gaseous substances of oxygen and hydrogen, of which it is formed. It kills animals.

By the lightning-flash between a cloud and the earth, which flash is merely accumulated electricity, all these effects are produced in extreme degrees. It may prostrate a whole flock of sheep; it often kills people who seek shelter under trees during a thunderstorm, because the human body conducts electricity more readily than the trees, which, by their height have attracted the flash. It rends great trees, splits rocks, shatters the towers and spires of lofty edifices, sets fire to ships, and may explode a powder magazine, &c.

But against all these modes of destruction, complete security is now attainable by the use of the lightning conductors devised by Dr. Franklin. The writer refers to this fact with particular interest, from having twice witnessed, during a voyage made in early life, before the adoption of the more substantial lightning-rods now generally supplied to great ships, the appalling occurrence of a ship insufficiently protected being struck by lightning. The first time was in the South Atlantic, where a mast was split, and of several men knocked down one did not recover; the second time was when the ship was at anchor in the Straits of Malacca. A part of the rigging was set fire to, but by prompt measures the ship was saved.

In this section we have considered the phenomena of electricity as producible by friction, or as rendered very active by accumulation in the Leyden jar and otherwise. In what follows we have to treat of other forms, still more important.

ELECTRICITY IN CURRENTS, called also *Voltaic Electricity.*

1198. It was not until the middle of the last century that the electrical machine was invented, and the Leyden jar, and the electrical battery, and that Franklin proved the identity of electricity and lightning. The public mind was by these occurrences excited and gratified in the highest degree, and wonder was felt that facts of such vast importance, and apparently not deeply hidden, could have remained unknown so long; but scarcely had this feeling cooled, when a new set of facts connected with electricity drew attention, soon to appear of still greater importance than those above referred to.

Galvanism.

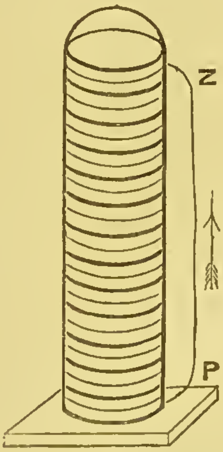
1199. Galvani, professor of anatomy in the university of Bologna, while making experiments on the bodies of frogs recently killed, observed that when metallic instruments were brought into contact in particular ways with the nerves and muscles of the animal, a strong action or contraction of the muscles took place, as if obeying the will of a living animal; and it appeared that the nerves served to convey an influence to the muscles, as the wires about an electrical machine convey electricity to distant parts acted upon. He at first conjectured that there was in animals a something analogous to electricity, and which he then called animal magnetism. After a time, however, it was discovered among the numerous inquirers who followed Galvani, that the cause of the motions observed was ordinary electricity, generated in the living body, and obedient in a degree to the will of the animal. The reflection was then made, too, that certain animals, to defend themselves against an enemy, or to secure other animals as their prey, can give a benumbing shock like that of a Leyden jar. The torpedo of the Mediterranean sea, and the electric eels (now so-called) of the great rivers of Africa and South America, are animals of this sort. Anatomy now finds that in the structure of all these animals, and obedient to their will, there is a powerful electrical apparatus.

In Glasgow, in the year 1824, the body of a malefactor, soon after execution, was subjected to experiments, and by touching the different nerves with electric wires, the body was caused to mimic alarmingly the actions of life and volition; as to raise the head, to distort the features, to lift the arm, to point a finger, and so on. In the living body it is known that by compressing, cutting, or destroying in any way the nerve leading from the central organ to a part, the action or function of the part is destroyed.

Proofs have been obtained also that many other functions of life, as well as the muscular, go on under the influence of electrical agency. An animal body hence comes to be regarded as a very complex structure, of which the numerous parts in action are harmoniously united with the brain and spinal marrow through the nerves connecting them.

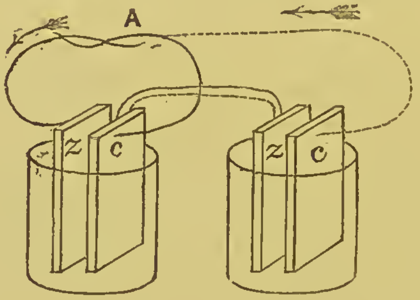
Voltaism.

1200. Volta, another Italian Professor, continuing the researches so happily commenced by Galvani, found that if pieces of two different metals, as copper and zinc, were placed in immediate contact, or near to each other, with acidulated water between them, they immediately became in a degree electrical; one of them positively and the other negatively; and, further, that if a metallic communication were formed between them through the air, as by suitable pieces of wire, a continuous electrical current began to pass by the wire, from one to the other; and the wire, while so serving, acquired very remarkable properties presently to be described. He concluded that the muscular contractions observed by Galvani were caused by such electricity traversing the nerves and muscles of the animal then acting as conductors.



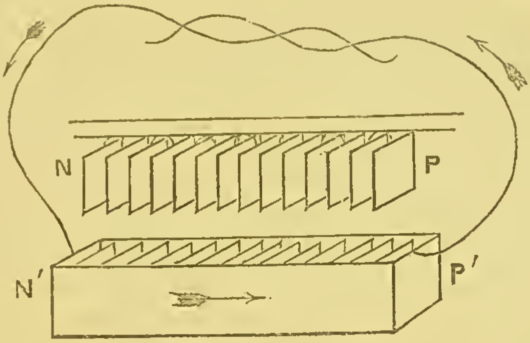
1201. Volta's experiments were first made with small round plates, or disks, of copper and zinc, which metals he found to be peculiarly suited to his purposes. He soon ascertained, further, that if he piled pairs of copper and zinc plates over one another, with a similar breadth of cloth moistened with acidulated water between the pairs—as one might pile up pairs of silver and copper coins, having a piece of paper between each pair, the electrical effects became stronger in proportion to the number of pairs—as many men pulling at the same rope exert by it a force of traction proportioned to their number. The adjoining figure represents a voltaic pile standing on a plate of glass, with copper at the bottom of the first pair, and, consequently, zinc at the top of the pile. The arrow shows the direction of the current in the conducting-wire moving from the bottom called the positive pole P, to the top called the negative pole Z.

1202. Much more convenient and powerful arrangements than this pile were soon devised by the original inventor, and by other distinguished philosophers, who then engaged in the same pursuit. One of these, which was soon very extensively employed, and, with some modifications, still holds its place, is here described, illustrating the principle of all.



The figures Z and C represent two metallic plates, about four inches square, one of zinc, the other of copper, standing side by side a little way apart, in a glass vessel ready to be filled with acidulated water. To each plate a piece of wire is soldered at Z and C, which two pieces can be brought to meet and touch at A, completing the circuit. The plates while dry, and not in contact below, give no sign of electricity, but if the wires above are joined and the liquid is poured in, a continuous current immediately commences in the direction C A Z. The two plates, so arranged, form an active pair or couple of a voltaic apparatus. If, instead of there being only one pair in action, others are added, as the second pair Z C, the strength of the combination, which is then called a battery, is increased in proportion to the number of pairs. The copper plate of the first pair is joined by a strip of itself to the zinc of the next pair, as here shown by the dotted lines, and the final plate of copper receiving the product of all the pairs sends the current by the circuit-wire towards the negative end of the battery Z.

1203. Instead of having a row of pairs in distinct vessels, resembling the two shown above, it is convenient to have a long trough of glazed porcelain divided into cells, as pictured in P N, below, and the pairs of plates of the two metals are affixed in due order to a wooden bar N P, so that they can be dipped simultaneously, when wanted, into the cells containing the acidulated liquid, and again lifted out when not wanted. When stronger effects are required than can be produced by one such trough, many troughs may be united. Sir Humphry Davy, at the Royal Institution in London, had a battery composed of two thousand pairs, with which he obtained the astounding results of which we have to speak in the sequel.



1204. Volta at first believed that the simple contact of dissimilar metals produced the two opposite electrical states. It was soon observed, however, that if one of them became at all oxidated, or underwent chemical action, as zinc so readily does when exposed to oxygen or acids, the production of electricity was proportionately greater. Further, it was found that the metal on which the acid acted most strongly evolved the electricity most readily, as is true of the zinc in most voltaic combinations. The zinc, for this reason, has been called the generating-plate, and the other plate, generally copper, the receiving or conducting-plate; and the current of electricity is assumed to be from the zinc to the copper within the troughs, and on the outside from the last copper plate in the trough, along the conducting-wire of the circuit, to the first plate of zinc, as indicated above by the arrows placed around. The greater the difference between the two metals of the pair, in relation to readiness for chemical action, the stronger is the voltaic current.

1205. It is one of the very striking facts in regard to the voltaic current passing from the positive end of the trough to the negative, that although the direct distance between them through the metals and liquids composing the entire trough, and which are all good conductors of electricity, is only of a foot or two, the current seeking to re-establish equilibrium never makes a retrograde movement, passing from P to N, but in an instant travels round the whole circuit of the connecting-wire or wires, even if they be hundreds of miles long, as from London to Edinburgh, or Paris, and back. It proves its momentary presence at any distant part of the circuit by ringing, as it passes, a bell, wherever placed, or doing other telegraphic work.

1206. Not less striking than the extent of the journey travelled in such a case, is the rapidity with which the movements occur, and their dependence on the electrical circuit of conducting substances being complete and closed, instead of broken or open. If the conducting-wire, near the battery or in any other part of its circuit, be purposely parted or divided, so that the two cut ends can be readily and suddenly disjoined and rejoined when desired, the act of so separating and rejoining many times in a minute is rendered as clearly sensible to a person watching at any other part of the circuit as to a spectator near the battery; and as a few up-and-down strokes of a pen form the letters of a written alphabet (the letter *m* requires six such strokes), so can equally simple movements of the key of an electric telegraph made in London mark instantly to an attendant at a telegraph station in Paris or Berlin any letter or combination of letters—as will be hereafter explained in detail.

In the voltaic trough or battery above figured, the connecting-wire of the circuit is shown departing from the copper of the positive pole P, and returning to the zinc of the negative pole N. The first zinc plate Z, on the left hand, excited by the acid and connection through a strip of metal with the first copper plate in the second cell, sends its electricity to that copper plate; from that the electricity is conducted by the liquid to the second zinc plate, and from thence in the same way, with increase at each step, the current reaches the pole P, to traverse the wire and do work wherever wanted.

1207. The electrical excitement, called also the *electromotive force*, produced in voltaic arrangements, is of very different strengths, according to the chemical nature of the metals or other solids, and of the liquids employed in the construction of the battery. It follows, therefore, that extensive and accurate knowledge of this subject is possible only to persons well versed in chemical science; and as, in the methodical study of the four fundamental sciences, explained in our preface, chemistry follows physics, the details of voltaic electricity do not belong to the present volume. Another volume, as large as this, would scarcely contain them.

Out of the science of electricity, although of such late origin, there have already sprung up several distinct and important branches of practical engineering; and although the science itself is yet far from being complete, the account here given of the battery of zinc and copper rendered active by diluted sulphuric acid contains what may satisfy the general reader, and may serve as a useful introduction to the more detailed study required for those who are to engage practically in some department.

1208. Having described briefly how voltaic currents of electricity can be excited, we proceed to treat of effects producible by them, under the heads of

Thermo-Electricity.
Electrical Heating.
Electrical Light.
Metallurgy.
Electro-Chemistry.
Electro-Magnetism.
Magnetism.
The Electric Telegraph.

1209. It was soon after Volta had made known his discovery of electric currents that Humphry Davy, in the laboratory of the Royal Institution of London, using the noble battery of 2000 pairs, supplied to him by the directors of that Institution, was enabled to exhibit new prodigies in science and art. He melted substances which had never been melted before. He produced light surpassing in intensity all other lights but that of the sun, and he resolved into their elements many substances which until then had been deemed absolutely simple or undecomposable, such as flint, lime, clay, &c., showing them to be so many distinct metals combined with oxygen.

Heating.

1210. Davy found that while the passage of an electric current through a large wire warmed it only a little, still in proportion as the wire used was chosen smaller or the battery employed was larger the heat was greater. The wire had first red heat, then white heat, and at last was melted, to drop as small globules on the ground. The metal platinum, which up to that time seemed unalterable by heat, became in the electrical current like sealing-wax in the flame of a candle.

Light.

1211. The conducting-wire of a voltaic battery being severed at any point, and pieces of pure charcoal of pencil form being fixed on the parted extremities, when the electrical current is allowed to pass between the charcoal points held at a short distance from each other, a light is produced in the gap or interval which the eye can no more bear to contemplate steadily than it can that of the sun. This light, being so intense or concentrated within a small space, penetrates an atmosphere charged with fog or mist to a much greater distance than the same amount of light proceeding from a collection of the strongest common lamps. Electricity has as yet been used in a lighthouse on the sea-coast only as an experiment, because of the difficulty of rendering the light uniform. The wasting of the charcoal points employed is unequal, but there is now hope that this difficulty will be overcome.

It is a question undecided whether other intense lights, as that of the combustion of common inflammable gas in the open atmosphere, or of iron wire in oxygen gas, or of the lately-discovered metal magnesium, in common air, &c.—are not all connected with electrical agency.

Electro-Chemistry.

1212. Soon after the important discoveries of Galvani and Volta, Davy in London, as already said, with the great Voltaic battery of the Royal Institution, proved that the earths and alkalies, until then universally held to be simple, unchangeable, elementary substances, were all compounds, formed of so many distinct metals and the substance called oxygen. Of these metals, that are now named,

Silicium	is the basis of		Flint
Calcium	,,	,,	Lime
Aluminium	,,	,,	Clay
Magnesium	,,	,,	Magnesia
Sodium	,,	,,	Soda
Potassium	,,	,,	Potash

Several of these metals are already in use for valuable purposes. Aluminium, for instance, which has the appearance of silver, but is much lighter under the same bulk than silver, is already substituted for it in various ways; and important purposes are now served by sodium, potassium, magnesium, &c.

With the battery referred to, Davy resolved water into its two elements of oxygen and hydrogen much more rapidly than had been done before. The wires of the battery, tipped with the more enduring platinum, when brought near to each other in water, drew asunder these elements, the wire from the positive pole taking the oxygen, and that from the negative pole the hydrogen. Separate inverted vessels placed over the wire-ends were soon occupied, each with its distinct charge rising rapidly into it in the form of small air-bubbles.

These analytical proceedings made manifest the great fact that the different elementary substances in nature have every one its peculiar relation to electricity, and led to the opinion that on such differences of relation probably depend what are called chemical affinities.

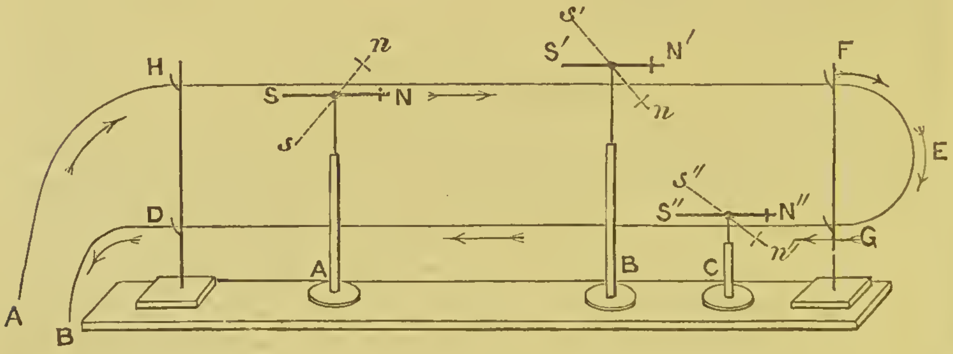
1213. The various discoveries referred to soon gave rise to new arts, as that of gilding and silvering objects by placing them, when fitly prepared, in a solution of gold or silver, and then connecting them with the negative pole of a voltaic battery, while the wire from the other pole entered the solution elsewhere. The precious metal is then precipitated or deposited over the surface of the immersed object, and adheres more strongly than if applied in any other way. Correct casts formed of cheaper metal or other material may thus be formed of coins, medals, or other objects, and may readily be covered with imperishable gold or silver.

Electro-Magnetism.

1214. If people marvelled at the discoveries of electrical currents and their effects made by Galvani, Volta, Davy, and others, they had to marvel still more when, in the year 1819, Professor Oersted, of Copenhagen, found that the natural direction of a magnetic needle, such as is used in the mariner's compass, was instantly changed by its being near a voltaic battery in action. Such a needle happened to stand on a table where the wire of a battery lay parallel to it. It had its usual direction of north and south, when the battery was not acting, but the moment the current was allowed to pass, the needle was thrown or deflected into a position across the wire, and so remained as long as the current continued. On the current being arrested, however, by unclosing or breaking the voltaic circuit, the needle immediately resumed its natural direction. Pursuing the investigation, Oersted found that the movements of the needle were produced as often and quickly as the acts of closing and unclosing the circuit could be repeated. He further ascertained that, near the wire, the changes took place as certainly and rapidly at any distance from the battery as near to it.

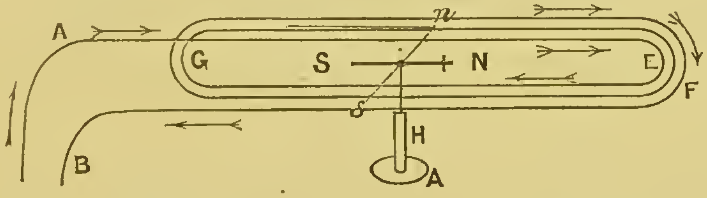
1215. These facts announced to some clear understandings the coming prodigy of the Electric Telegraph. It was thought —and the thought is now realized—that as the letters of a written alphabet, by which all words, and, therefore, all ideas, can be expressed, are made by a few short strokes of a pen up and down (the letter *u* has five such strokes, the letter *m* has seven), nearly so might the letters be indicated by slight movements from side to side of a key suddenly closing and opening a voltaic circuit. It is now in reality by such movements that the so-termed "*Latest Intelligence*," arriving in London during the night or early morning, is in a few minutes, through the telegraph, spread to stations all over the kingdom, and that the inhabitants of York, Edinburgh, and Dublin find in print on their breakfast tables the same paragraphs which are being read in the morning papers of London.

1216. The relations between the magnetic needle and voltaic current are not, however, quite so simple as from the above statement persons might at first suppose, as will appear in the following paragraph :—



If the line A H F represent part of the conducting wire-circuit of a voltaic battery, running from south to north, supported by the standards H and F, and if two magnetic needles, moveable on pivots, are placed near it, of which the letters S N and S′ N′ mark the south and north poles, one of these needles being *below* the wire and the other *above* it—on the instant when the electric current is made to flow from H to F, as marked by the arrow, both needles assume positions across the wire, but the one below turns its north pole, N, to the west, as shown by the dotted line, *n* s, and the other above turns its north pole, N′, to the east, as also here indicated. Then, if the wire be bent down at F, and brought back in the direction F E G D B, reversing thereby the direction of the current, a third needle, N″ S″, placed near and above the low wire, G D, instead of taking a contrary position to the needle above N′ S′, because the direction of the current is reversed, will take the same position as N′ S′, here shown. This apparently inconsistent or contradictory result was for a time a puzzle; but it was soon perceived that the force operating on the poles of the magnets, near the voltaic wire, was not urging simply east or west, but all round the wire, in the direction of a screw or spiral. This direction may be described as being always towards the left side of a small animal supposed to be swimming with the advancing current, head foremost, and looking always towards the needle. This fact becomes apparent if the needle be supported vertically on a horizontal axis, as in the electric telegraph. In a circulating or rotatory motion, as of a wheel, the parts on one side of the centre or axis are ever moving in exactly the contrary direction to those on the other side. For instance, the minute hand of a clock, which at noon is moving eastwards, at six o'clock in the evening is moving westwards.

1217. A remarkable consequence arises from these facts, namely, that if the wire of the voltaic current A E, over the needle S N, be bent down at E, and carried back to G at a short

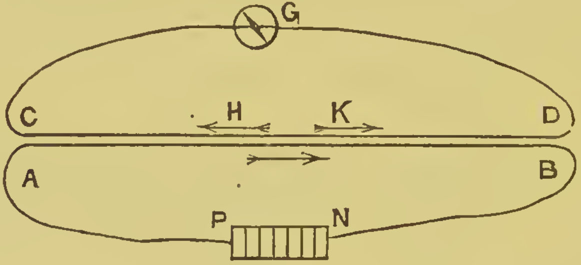


distance below the needle, instead of counteracting the influence of the upper part of the wire, A E, as might be expected from its electric current being in the contrary direction to that in A E, it doubles the effect. The part of the rotating or wheel-current about the upper wire, which acts on the north pole, N, to drive it westward, coincides with that of the upper part of the current about the lower wire, also moving westward, so that the two coincide and assist each other.

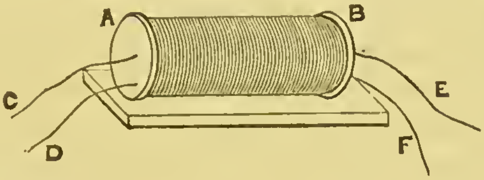
From all this it follows that if the wire at G is bent a second time, and carried back above the needle towards E, as shown here, and from thence again is bent round at F, the deflecting force is quadrupled, and so on, if the turns are farther multiplied. By this device of the coiling the wire around the needle a very feeble voltaic current at the source is rendered so strong to deflect the needle, as to cause a distinct rattle or clink of it on an ivory pin, placed to limit its motion. And it explains why a voltaic battery in London of moderate strength, having a conducting wire of hundreds of miles in length suffices, when aided by coils, to work satisfactorily the needles of the most distant as well as of various intermediate stations.

1218. A fact which was less expected than any of those hitherto described is, that if the conducting wire of a voltaic battery be formed into a long, hollow coil or spiral, within which a thick bar of pure soft iron is placed, that iron is rendered a powerful magnet so long as the current flows, but instantly returns to its natural state of mere iron when the voltaic circuit is disjoined or broken. And if, instead of a bar of soft iron, one of hard steel is placed within the coil, the steel is rendered a permanent magnet of equal force. Thus artificial magnets are now formed of much greater strength than any natural magnet.

1219. A very important fact in regard to electrical currents is that a wire, as A B, while serving as a conductor connected with



a voltaic battery N P, or a strong magnet, if placed near another insulated wire, C D, but not touching it, causes in that other wire at first a strong current moving in the opposite direction to its own—the battery current is shown by the arrow between A and B, and the induced opposite current by the arrow from H to C. The current of induction, however, soon ceases, as proved by the needle of the galvanometer G giving no sign; but, singularly, when the primary current is suddenly arrested by breaking the battery circuit, a strong recoil current, K D, in the direction of the battery current takes place for a moment in the wire C D. Thus, by making and breaking the circuit at short intervals, there is an equally frequent repetition of strong opposite currents capable of producing important effects. Ruhmcorff has manufactured an admirable machine of this nature. A great length of insulated wire, the ends being E and F, of moderate size, is wound round a bobbin, A B, and then a much greater length (many hundreds of feet) of smaller wire is wound over the first quantity (the ends being C and D), and a battery sends its current through E F. The recoil current from C D is produced when that of E F is stopped. Effects of intensity are produced by such combination rivalling those of batteries of Leyden jars.



The hypotheses or conjectures of scientific inquirers regarding electrical currents, the intimate constitution of material masses, and the forces which hold the elementary particles of masses together, are yet far from being satisfactory. Almost all inquirers, however, now agree that there must be, although unperceived by human sense, a medium of most subtle nature pervading general space, and closely connected with the phenomena of light, heat, and electricity. If the fact be so, our globe is wholly immersed in it, performing all its motions therein, as of its diurnal rotation and its annual revolution, &c. Now, it is common knowledge that in a perfectly calm atmosphere a man on a galloping horse has a pressure of air on his face exactly as if he were at rest, and the wind were blowing upon him with the speed of the horse. Similarly, if a globe of any substance be immersed in still water, and be made to rotate or turn on its axis there, any small bodies adhering to its surface, particularly near its middle or equator, would be pressed upon as if a whirl of water having the velocity of the surface of the globe were acting upon it. Then, this earth being a globe rotating with a speed at the equator of more than a thousand miles an hour (for the circumference of the globe is nearly twenty-five thousand miles, and the rotation is completed once in twenty-four hours) there is almost a certainty that, while the earth's motions continue, there must be operating near its surface pressures or other effects analogous to those of the wind produced on a rider during a calm by the motion of a galloping horse, or to the effects of the trade winds, caused by the earth's rotation. The explanation of electrical and magnetical phenomena may become more complete when this matter is fully investigated.

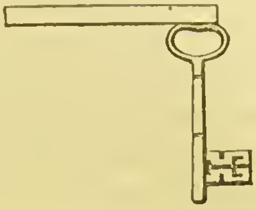
1220. In the *science* of electricity, as distinguished from the useful *applications* made of it, the chief advances since the time of Oersted have been made by Professor Faraday. It was he who first made manifest the intimate relations between electricity and magnetism, which have led to magnets being now substituted in many cases for the voltaic battery. It was he who, by obtaining the electrical spark from the bodies of the fishes now called electrical, proved that their structure included a powerful electrical apparatus. It was he who showed that many substances besides iron were subject to magnetic influence; and that most substances, indeed, when placed, with full liberty to move, between the poles of a strong electro-magnet, assume a direction either from pole to pole or diamagnetically across that line.

Magnetism.

Formerly, in systematic treatises on Natural Philosophy, magnetism stood apart as a very distinct branch of science, singularly at variance with the general course of nature; but recently, since more extended knowledge of both electricity and magnetism has been acquired, the resemblances between them are found to be so numerous and close, that nearly all the phenomena can be referred to the same influences.

When the most obvious facts of magnetism first attracted notice, nothing could appear more strange or unlike common nature.

1221. A dark-coloured heavy stone, now met with in many parts of the earth, but first observed near a village called Magnesia, in Asia Minor, from which it got its name of magnet, was found to have the singular power of drawing towards it pieces of iron or steel, and of lifting them into contact, and there supporting their weight for any length of time.

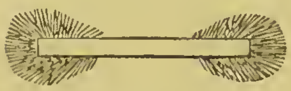


On rubbing such a stone against rods of steel, its power of attracting iron, as well as other powers, was communicated to the steel, and then from one bar of magnetised steel other bars without end could be magnetised without there being any diminution of force in the original or giving bar. A good illustrative experiment is to show a common iron key hanging by magnetic force to the end of a magnetised bar, as here pictured.

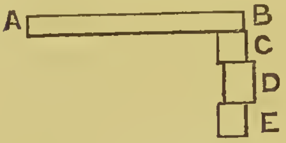
Such a stone or magnetised rod of steel, if suspended by a string or poised on a pivot, so as to have freedom of horizontal motion, soon places itself with one of its sides or ends, and always the same, towards the north pole of the earth, and with the opposite, consequently, towards the south pole. Its own corresponding sides or ends so discovered, are called the poles of the magnet. If the stone or needle be by any force disturbed from the position so taken and then left free, it always of itself returns to the same.

This property, called the polarity of the magnet, has often been referred to as one of the most curious facts in nature, and is of vast importance to humanity. Men are often placed in such circumstances that their safety and even life may depend on their being able to judge correctly of the directions, north and south. A man, when there are dangers near, may be suddenly enveloped in a thick fog or in a blinding fall of snow, or he may lose his way in traversing a forest or on crossing an extensive plain without distinguishing objects on its surface, or in a boat he may be driven by a storm out of sight of land; in such cases life may be lost if he judge erroneously of his place or of the direction in which he moves. In any such dilemma, a magnetic needle carried in a seal attached to his watch would insure safety. Had the mariner's compass, which is only a larger needle fitted to bear the tossing of the waves, not been invented, intercourse of nations by sea could scarcely have taken place. In remote past times nothing could have seemed more incredible than that a stone would be discovered in the bowels of the earth, which could point always with certainty to the pole, where highest human sagacity without it would search in vain.

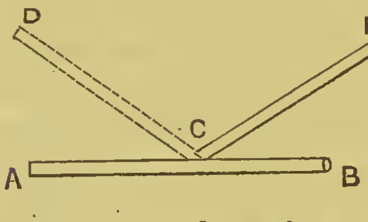
1222. If two poised magnetic bars are brought near to each other, the poles of the same name, north or south, are found strongly to repel each other, and the poles of different names strongly to attract; but either pole is equally attractive of nonmagnetised iron or steel. In these facts there is a striking resemblance to the phenomenon in electricity of bodies similarly electrified, whether positively or negatively, being held apart by strong mutual repulsion, while, if dissimilarly electrified, they as strongly attract, and either of them, if separate, equally attracts all non-electrified bodies.



If a magnetic bar or needle be placed for an instant among iron filings and then be lifted, it lifts with it a considerable quantity of the filings cohering around the ends in tufts or lines of particles as here shown, but there are none cohering near the middle of the bar. This experiment indicates the different force of the attraction at different distances from the poles of the magnet, and the non-attraction in the middle part about the so-called equator.



Simple contact or near approach of a magnet, and a piece of soft iron, renders the iron for the time magnetic—nearly as any insulated conductor of electricity, if brought *near* to a highly-electrified body becomes electrical, through the influence called inductive, described in Art. 1219. Thus, the magnet A B attracts and supports the piece of iron C, and that becoming magnetic, similarly supports the second piece D, which again can support E. It is in this way that the lines or threads of iron filings in the preceding experiment are formed. None of the pieces of soft iron, C D E, retain anything of the magnetic quality after the contact ceases. Pieces of steel after a time might retain a portion.



1223. A magnetic steel-bar, however, if fitly used, imparts its properties permanently to other steel bars without losing any part of the power which it possessed itself. The common procedure thus to magnetise is, to apply at the centre of the new steel bar, as A B, laid on a table, one end of a strong magnet C E, held obliquely as here shown (at an angle of about 30°), and then to draw the magnet steadily along, held at the same angle, to B. After repeating this touch several times on one side, the other end of the magnet E is brought to the centre of the bar C, and is drawn along to A, and an equal number of passes being made as from C to B, the bar A B is permanently magnetised. Instead of thus using a single magnet C E for both ends, two similar magnets may be applied at the same time.

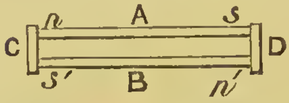
If a sheet of paper or a plate of glass be placed over ā magnet on a table, and iron filings are showered over the level surface from a sieve, on then tapping gently on the paper or glass, the iron filings assume more or less an arrangement of curved lines, indicating the directions in which the supposed currents of magnetic force operate.

1224. A bar of iron or steel by lying long near a strong magnet may acquire a degree of the powers of the magnet. Now, this great globe of earth which man inhabits, by the influence which it exerts on the compass needle, is proved to have magnetic influence, and hence has been called a great magnet. Possibly the masses of iron ore in the bowels of the earth, called natural magnets or loadstones, may have become magnetic through this influence. As voltaic currents of electricity produce the strongest magnets yet known, and as artificial rotation of plates of metal, or other substances, can produce electrical and magnetical currents near them, it may be supposed that the swift rotation of the earth may be concerned in producing or modifying its magnetical condition.

It is known that a wind of forty miles an hour, even in a perfectly calm atmosphere, blows in the face of a passenger in a railway train who puts his head out to look forward, and if a bent tube be held out with its mouth turned to the wind, the rush of air entering the carriage through it could strongly turn a windmill wheel, and thereby perform mechanical work. The trail of smoke seen behind a steamship or a railway locomotive was at first, by many persons, supposed to prove a wind a-head having that speed, but it is merely the smoke remaining in a more still atmosphere behind the engine which is passing away from it.

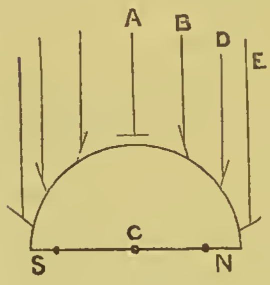
1225. It is to be noticed here that the action of the earth upon a magnetic needle is merely *directive.* A needle floating on a cork support soon points north and south, but it does not approach either the north or south side of the vessel in which it floats. The explanation offered is that a pole of the earth which attracts one pole of a magnet repels the other pole, and so nearly with the same force, that the magnet is not removed from its place. The magnetic action has relation to distance, but the difference of distance from a north pole of the earth to the two poles of a magnet is less than a millionth of the whole distance, and, therefore, is without sensible effect.

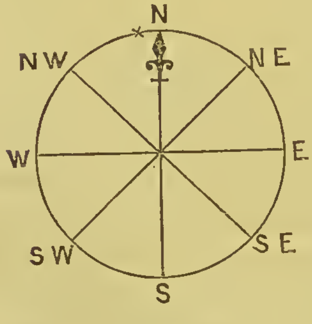
It is for this reason that two magnetic needles or bars, A and B, of equal strength, if fixed together with their poles reversed, that is, with the north pole of the one placed near the south pole of the other, exactly balance each other, and assume no particular magnetic direction, while they still exert their separate powers on objects near to them. Such double needle is called *astatic* (*without fixed state*).



The child's toy of a tiny figure of a swan having a magnetic needle within its body, which immediately obeys the attraction of a magnet held in a hand near it, is a good illustration. The north pole of the concealed magnet, near the swan's neck, is attracted by the south pole of the magnet held in the child's hand, but from the other pole the swan quickly turns away as if in fear. If within the swan there were an astatic needle, the bird would appear to pay no attention to the hand magnet.

1226. In the mariner's compass the needle is so balanced on its pivot as to be horizontal in all parts of the earth; but if the needle is free to turn also on a horizontal axis, it will be horizontal only near the equator, but at other places it will dip down, pointing to the nearest magnetic pole, as here shown at B, D, E, &c. A needle so arranged is called a *dipping needle*.





1227. It is an important and singular fact, to be noted, that the compass needle does not point exactly north and south, that is to say, the magnetic poles do not quite coincide with the poles of geography, and that the amount of deviation called the "variation of the compass" gradually and slowly changes, being sometimes a little to the east and sometimes a little to the west of the earth's pole. The deviation, however, is easily ascertained by referring to the stars. In London, at present, the needle points about 19° to the west of north. In the year 1657, beyond two hundred years ago, there was in England no variation. This declination differs considerably in different parts of the earth. A satisfactory explanation of this phenomenon has not yet been given. In pocket compasses it is common to place a mark on one side of the north point (here a minute cross), to indicate how much the magnetic north is to one side of the true north.

1228. Among the close resemblances between magnetic and voltaic action may be noticed such facts as the following:—If a magnetic bar or needle be broken or divided into parts, each part is found to be still a complete magnet, having its north and south poles, only more feebly. So if a voltaic battery of many pairs of plates united in a row be divided, any part still manifests the same powers and poles, only weaker in proportion to the diminution. The conducting wire of a voltaic battery, if formed into a long helix or spiral, and supported so as to have freedom of motion about a centre, sets or comes to rest in a direction north and south, as a magnetic bar does.

In ships built of iron, or having iron plates or bars about them, there is a disturbing influence on the compass, which has to be counteracted according to the nature of the case.

1229. There is no perceivable difference in the weight, size, or appearance of a steel bar when in the state of soft steel, and when afterwards tempered to great hardness by being heated, and then suddenly cooled in a cool liquid. There is as little difference between a steel bar or needle in its ordinary state and after being rendered magnetic. There must be produced in both cases some change in the arrangement of the atoms or ultimate particles of the mass.

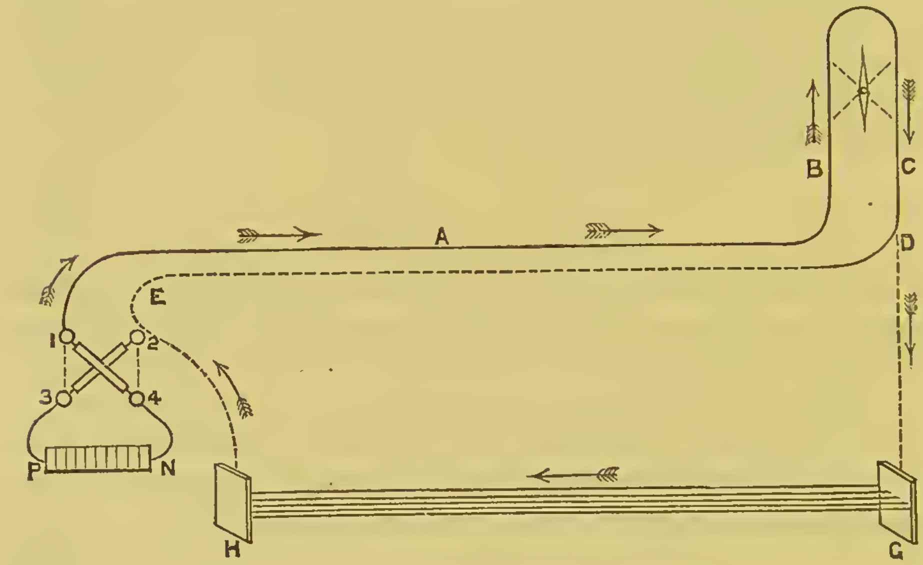
The Electric Telegraph.

1230. This admirable invention is an arrangement of parts fitted to produce certain results in accordance with the laws of electric and magnetic force explained in the preceding pages. People, generally, are now aware that among these results are the following:—Information of importance to individuals or to the public is sent from any part of a country to any other, and questions are asked and answers returned, all within a few minutes. When the signs of coming storms, now much better understood than formerly, are anywhere observed, a telegraphic notice, which travels a thousand times faster than any storm, can be sent to places in the direction of the storm's progress, so that useful precautions can be taken. In sea ports, ship-captains so warned can delay sailing until the danger has passed. If telegraphs on railways did not exist, constantly passing information along the lines, of the arrival and departure of trains, not half the present traffic on the lines could be safely carried on. When at the Observatory of Greenwich, near London, the clock marks the instant of noon, or any other time, the fact through a telegraph connected with the clock is declared at many other important stations, as Liverpool, York, Glasgow, Edinburgh, where by the dropping of a ball obeying the telegraph, in a conspicuous place, or the firing of a gun, the information is widely spread. A gun fired on the castle hill of Edinburgh by an electric wire, nearly a mile in length, stretched high in the air from the Observatory, is heard for many miles around. Shipmasters about to sail, hearing such a report, can set their chronometers exactly to Greenwich time; and clocks and watches over the country, which maintain order in the whole business of society, may thus be regulated.

Construction of the Telegraph.

It consists of several parts, as below enumerated.

1231. A voltaic battery, P N, or strong magnet, to evolve or generate the electricity. The letter P marks the positive pole of the generator, and N the negative. The line P A B indicates the insulated conducting wire leading from the positive pole of the battery used by the sender of a communication to the needle B C at the receiving station, and from thence back again by the

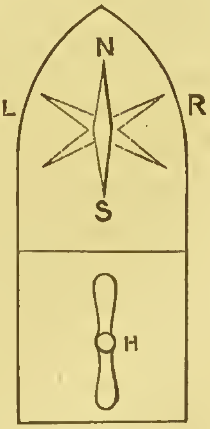


wire C D E N to the negative pole N. Along the sides of railways these wires are conspicuously seen, supported in the air on lofty poles, and the insulation of the wires is effected by strong rings of glass or porcelain fixed near the top of the poles through which rings the wires pass.

The figures 1, 2, 3, 4, mark the situation of some one of the mechanical contrivances by which the sender of a communication can instantly either close or open or reverse the great conducting circuit, on the continuity of which the action between the stations depends. Of these contrivances, called the *Reotropes*, (*current changer*) or *permutator*, there are many forms, which need not be described here in detail. Both wires of the battery have a gap in them, as between 1 and 2 for the going wire, and 3 and 4 for the returning wire, and the cut ends have nobs on them between which the reotrope acts as two draw-bridges, which according as the handle H is turned to the right or left makes nob 2 a part of the wire A B or of E D, and at the same time makes nob 4 a part of E D or of A B. The key, when standing upright or vertically, leaves both gaps open, and, therefore, without voltaic action for the time. Turning the key fully from one side to the other reverses the current.

By this arrangement the sender can open and shut the circuit and can reverse the currents at will with great rapidity, and with these powers he can signify all the letters of an alphabet to a correspondent or co-operator at a distance as clearly and quickly almost as they can be written with a pen. As many systems of an alphabet of mere motions have been devised as there are alphabets of visible characters.

The telegraph needle being within a box, L R, like the case of a chimney-piece clock, an index on its axis appears on the outside like the hand of a clock. The key, or handle, H, below, has the like motion to the left, L, and to the right, B, as the needle. Then to produce an alphabet, one movement to the left, of the needle's north point or pole N may signify A, two such in quick succession may signify B, three such may serve for C, four such for D; then like movements to the right would mark four more letters, then these signs made on one side, succeeded or preceded by one on the other, would form eight more letters, and other simple combinations would give the remainder of the alphabet. It may be recalled that



to make single letters of the written alphabet many movements of the pen are required; the letter *m*, for instance, has four upward and three downward motions. These statements will give to any reader a general conception of the process of signalling language by telegraph, and more than a general conception is not intended here.

The conducting wire of any telegraph, from London to Edinburgh for instance, may take the form of a coil at any intermediate stations, and may work needles there just as it does at the extremes, so that the same piece of news may be delivered in many places at the same instant.

For the first telegraphs a second wire was always provided, as the return conductor, leading from the place to which a message was sent, back to that whence it came; but the important discovery was soon made, that if the current pass by a well-insulated wire from one station to another, the natural earth will serve perfectly as a return conductor, and thus much of the expense is saved. The figure at Art. 1231 shows this simple arrangement. P N is the voltaic trough or battery, P being the positive pole, N the negative, and P A B the conducting wire of the positive electricity from the sending station to the receiving station B C. At D the current, instead of returning by the wire D E N, descends to a broad plate of copper G buried in the ground, and from that is conducted by the ground itself (as here represented by several fine wires) to a similar plate buried near the battery at H, from which it rises by a single wire to the negative pole N. By the side of railways, existing all over the country, the telegraph poles are now seen supporting the numerous wires required for the great intercourse going on, to and fro, while the ground is serving generally as the return conductor.

In beginning a telegraphic communication, the sender rings a bell at the distant station by a touch of the telegraph key under his hand, which causes the electric current to render a piece of soft iron at the distant station magnetical for a moment, and so withdraws a detent to allow a weight to ring a bell, as occurs in the common alarum clock. It affords a striking proof of the rapidity of the electrical movement to find that the person who by a touch instantly rings a bell in Edinburgh may have his own bell as quickly rung in reply by a touch given in Edinburgh, which tells that the correspondent there is at his post.

1232. But the needle-telegraph above described is only one of numerous mechanical arrangements now extensively employed, by which letters, and, therefore, any words and thoughts can be signalled to a distance with lightning-speed. The needle form was the first publicly established, and it is still extensively used in Britain. For it the world is indebted to Professor Wheatstone, whose correct science and exhaustless mechanical ingenuity have produced also not a few other novelties of high value, as the *stereoscope*, which now delights every eye, and the *concertina* and *symphonion*, which delight all who feel the charm of music. There are few studies in practical mechanics more interesting than that of the ways in which ingenious men have sought best to obtain the objects of electric telegraphy. A whole volume like the present could contain the details of but a part of them. We shall glance at two other forms of telegraph.

1233. A simple arrangement for letters was introduced in North America by Dr. Morse, soon after his return from this country, where he had been studying the subject. It makes on paper simple marks as legible as the letters of common alphabets. A long narrow slip or ribbon of paper is by clockwork uniformly unwound from a drum or reel when the telegraph is in action, to pass under a steel point fixed to the end of a lever-magnet, worked by the electrical current. The point descends like a pencil to press on the paper whenever the key of the telegraph is turned. It can make on the paper either a mere dot or a line of any desired length, according to the duration of the contact allowed; and the letters consist of dots and lines variously combined. There is the great advantage in this and other marking forms, that they leave a permanent record of the communications sent, to be referred to afterwards, if required.

1234. Several more complex arrangements have been devised, which print the communications in the common Roman letters or others. One of the most interesting of these was that early proposed by Wheatstone, and recently brought by him to high perfection in the service of the "*Universal Private* Telegraph Company." The company is so called because parties using its instrument have a distinct wire or conductor exclusively for themselves. The instrument is called also a dial-telegraph, because on a dial-plate, like the face of a watch or clock, the letters of a common alphabet appear all round, in lieu of the usual marks for the hours. There is over the dial a turning arm or pointer like the minute hand of a clock, which the sender of a message arrests to mark in succession each of the single letters which spell the words to be conveyed. The attendant at the distant station has before him a similar dial-face, on which the movements of the hand or index perfectly correspond with those of the sender. Persons using this telegraph have not, either for sending or receiving a message, to learn a new alphabet, and in a few minutes any one can be shown how to use it. Further, for this telegraph the electric currents are produced by a steel magnet, which saves the expense and delay of managing a voltaic trough with its liquid. One form of it prints permanently the communications sent by it.

The conducting wires of this telegraph in towns are placed chiefly above the roofs of the houses in the form of a few small ropes supported on poles. Those ropes may contain each fifty or more distinct insulated wires, the ends of one of which are brought down to the two houses or offices placed through it in communication. The value of such simple and ever-ready means of intercourse is great between central public offices and their branches, as for the post-office, the police, fire-brigade, bankers, &c., also between the principals of extensive manufacturing or commercial undertakings and their agents, or between any friends living apart who may desire to have frequent intercourse without leaving home. The expense is a rent-charge of so much by the year for the exclusive use of a wire and dials, and the lease may be abandoned at will.

1235. The submarine telegraph, which connects countries separated by seas, is of an importance which can scarcely be overrated. It differs from the forms used on land, chiefly in the fact that the conducting wires have to lie deep in water, and yet to be secure against the contact of water. Elastic gum or caoutchouc proves to be a good inner defence, which has to be protected externally by coverings of pitched hemp and strong iron wire, so as to form a cable not likely to be injured by severe strains or rocky bottoms. Many submarine cables are now, after early failures, serving perfectly.

Since the invention of the electric telegraph this world may be regarded almost as a new world for man, from which the obstacles to human advancement depending on distance have been almost wholly removed.

ASTRONOMY.

PART V.

THE PHENOMENA OF THE HEAVENS.

ASTRONOMY is a Greek word composed of *aster* a star and *nomos* law. It was used to signify what could be learned respecting the distant objects visible in the sky, as to their distances, sizes, motions, and relations to this earth. The word has passed into modern languages like many other scientific terms, because the earliest scientific writings in Europe which have been preserved to the present time were in the Greek language.

Man's knowledge of the universe around him has been slowly and gradually acquired. A person born into it can know only what his own senses and experience, or the experience of others reported to him may teach, nearly as happens on a small scale to persons thrown on any strange land. Thus, although the human race has existed on the earth now for thousands of years, it is less than four hundred since the inhabitants of Europe and Asia became aware that there lay to the westward from Europe another region nearly as extensive as their own, which has since been called by them the New World of America. The time is still shorter since they discovered the passage by sea round the Cape of Good Hope from Europe to the countries of India and Eastern Asia. Then, in regard to knowledge of Nature's laws and the arts founded on them which now distinguish civilized from savage men, the acquisition has been similarly slow. The arts of rapid spinning and weaving, of making carpenters' tools, of forming an alphabet of sounds for written language, of producing gunpowder, telescopes, steam-engines, and innumerable other such things, have all gradually sprung up as fruits of man's ingenuity and industry.

There have been two main causes why useful knowledge acquired and applied by the people of one locality did not more quickly than has happened spread into others. The first was that in early ages there was generally enmity and even open war between neighbouring communities, the name of foreigner in them often meaning also enemy. The second was that the art of writing, by which knowledge can be preserved correctly as well as permanently, was not an early invention, and it spread slowly. Records depending on oral tradition soon become inaccurate and often are perverted. Witness the mass of monstrous fables commonly called the early history of Greece and Rome, but which, nevertheless, formed the basis of the popular religions of these countries.

People accustomed to the climate in which they have been born and have lived, and to the mental condition of the race of men of which they themselves are members—Caucasian, Mongol, Chinese, African, &c., when they pass to other countries and find the personal appearance of the natives, the language, dress, manners, religious opinions, and so forth, strikingly different from their own, are apt to deem what they have always known, to be nearer to simple and perfect nature than what may seem to them strange, odd, absurd, &c., among the new acquaintances.

1236. A good illustration of how much men's knowledge of what is really according to nature depends on their own experience, was offered during an interview which took place between an Indian prince, who had never left the warm region in which he was born, and the captain of a ship from Europe, recently arrived by the newly discovered route of the Cape of Good Hope. The prince had listened with singular interest and satisfaction to the account given of the ways of Europe in regard to government, the affairs of peace and war, new scientific inventions, and so forth; but when the stranger had to speak of the winter season, and to say that the cold was so intense as to render the water of the rivers and lakes hard and so strong as to bear the weight of men and horses walking upon it, the prince began to suspect the truth of the reporter. When it was further stated that instead of rain falling during that season there came down white soft flakes like feathers, in such quantity as to cover the earth to a depth of many feet, in some places even to conceal houses and trees, the prince no longer doubted that he had an impostor before him, who, further, was grossly insulting him by supposing him weak enough to believe assertions so contrary, as he said, to all human experience and common sense. He ordered the man instantly from his presence.

An educated person now, reflecting on this narrative does not find in it proof that the prince was of weak mind, but was of narrow experience. And he may reflect that even in Europe about the same time persons, deemed the most enlightened of the day,—university professors, divines and statesmen,—had manifested ignorance as dark, respecting much more important things than ice and snow, and had resented still more strongly the apparent insult offered to their wisdom and dignity by individuals who had discovered new truths important to the world, of which they were seeking to spread the knowledge. Reference is made here to the labours of Columbus, in regard to geography, and of Kepler, Copernicus, Galileo and others, in regard to astronomy.

1237. It was near the beginning of the fifteenth century of our era that an Italian mariner, Christian Colon or Columbus, of much experience and rare sagacity, declared his conviction that this earth had not, according to the common belief of the time, an upper surface nearly plane and level of vast breadth, surrounded by an ocean of unknown extent, but was a great globe, or ball, balanced in open space and offering all round fit habitation for man. He held that on the side of this globe opposite to Europe the regions called *Indian* or *the East* lay. At the same time he offered to conduct an expedition across the hitherto unexplored western ocean, the Atlantic, having assurance of so reaching, by a more convenient way than any other, the regions above referred to of Eastern Asia. The Portuguese, Spanish, and other governments were in succession applied to by him for aid, but all of them were incredulous. They submitted the project to the scientific authorities of the time, but these, without exception, declared that Columbus must be an insane visionary and rash adventurer, whose notions were contrary to common sense and to the authority of the Bible. One party thought to settle the question at once by remarking that the people on the other side of the world of Columbus must be standing with their feet up and their heads down; that ships there would have to sail with their masts undermost, and that rain would have to *fall upwards.* The project was declared to be utterly absurd, and advice was given that the voyage should not be attempted nor even allowed. The prudent replies made by Columbus to the various objections were all in vain, as were also his appeals in other quarters for countenance and help—until the spirited Isabella, queen of Ferdinand of Spain, after an interview granted to Columbus, was so convinced by his explanations and eloquence that she offered to pledge her jewels to meet the expenses of the enterprise. Ships were fitted out, and the experiment was made, of which the glorious results are known to all. The new world of America was then discovered, impeding somewhat the most direct way by sea from Europe to Asia, but proving that all the reasonings and anticipations of Columbus were sound. At the present time, ships are arriving every day from countries of the far East, as Australia and New Zealand, completing a voyage round the globe, by coming home by the southern cape of America. In almost every library now there is placed a mounted globe, which is a perfect miniature model of the great earth on which we live, exhibiting accurately the form, dimensions, and relative positions of all the countries on its surface; and which, if set in the sunshine in a proper position, shows exactly the parts of the earth on which the sun is at the moment shining.

1238. If the stranger from Europe when before the Indian prince, as above described, could have filled a cup with water from a neighbouring fountain, and immersed it for a few minutes in any of the freezing mixtures now in common use, he might have thrown the contents of the cup on the table as a lump of ice, convincing all present of the truth of what he had said. Or the evidence of some intelligent Indian witnesses after a visit to Europe would have answered the same purpose. The facts of Astronomy, to persons of limited experience or defective education, when stated shortly as here below, would appear still more incredible than the existence of ice and snow did to the prince, and indeed, might be deemed more like the wild dream of a disordered brain than a statement of realities. The astronomer says, "This earth which we inhabit is a vast globe balanced in open space, turning rapidly on its centre, and ever wheeling round the sun, being one of many like globes so circumstanced, and the sun being one of many like bodies giving light and heat." Yet all this and other kindred facts are proved beyond doubt by the momentous discoveries made in late times through powerful telescopes, and by the evidence of thousands of intelligent mariners who have now sailed round the world in all directions, and have left recorded in their log-books, written from hour to hour, the important phenomena witnessed by them.

The distinguished Greek philosopher Aristotle, whose authority was great, for good and for evil, for more than two thousand years, had laboured before the invention of telescopes and other apparatus, and before correct astronomical observations had accumulated. Not being able, therefore, to discover much of order among celestial phenomena, he concluded that the laws which governed them differed essentially from those ruling below. This view having been widely accepted, influenced unfavourably astronomical research. At last the momentous discovery was made by Isaac Newton, that there exists among all ponderable substances a mutual attraction, which he named *gravitation*, which, as the particles of water are drawn together into a drop of rain or dew, draws together into a larger globe the materials of this earth and of the other planets, and modifies all the motions going on among visible bodies. Thus it was proved that the same laws of phenomena prevail through nature, both celestial and terrestrial. They appear to be different chiefly because the scale among the former is so prodigiously greater than among the latter. Men are familiar on earth with exact miniature counterparts of much that is going on throughout the boundless expanse of space. These general laws have been considered in the preceding parts of this volume, principally as manifested among terrestrial things. The object of the present chapter is to show them similarly governing among celestial things.

EXTENDED OUTLINE OF THE FACTS OF ASTRONOMY.

Section 1. *This* EARTH *is a globe of nearly* 8,000 *miles in diameter, of which the substance is held together in rounded form by the mutual attraction of all its particles, as shown on a small scale in drops of rain or dew. The earth is distant nearly* 30 *times its own diameter from the next nearest body to it—the* MOON.

Section 2. *It is rotating, or turning about its centre, like a ball hanging by a twisted cord, and by being in view of the Sun it has the changes of day and night.*

Section 3. *It revolves or travels round the* SUN, *as a stone in a sling round the hand of the slinger, once in* 365 *days and a fraction, the period called a year, and so has the change of the seasons.*

Section 4. *It is accompanied by the smaller globe, the* MOON, *which revolves round it as it revolves round the Sun.*

Section 5. *It is the third as to distance from the sun, and length of year of a series of like globes called* PLANETS, *some being larger and some smaller than it, those smaller having no moon, and the larger having more than one. Around the Sun there revolve also, in very elongated orbits, many transparent masses of little density, called* COMETS.

Section 6. *The* SUN *himself is the nearest to this earth of unnumbered similar self-luminous bodies, existing through boundless space, of which* *the others, because much more distant, appear to human sight very small, and called* Stars.

Section 7. *The motions or changes of place going on among the heavenly bodies are so regular, that astronomers can now tell what their relative positions have been through long past time, and will be through the future, and, so can predict the exact time of coming* Eclipses, Occultations, Transits, High *and* Low Tides, *and other such phenomena—as is set forth in almanacs published by authority, years in advance of the events.*

Section 8. *There are innumerable proofs on earth that during the lapse of ages great changes have taken place upon it in regard to temperature, the distribution of land and water on its surface, and the kinds of animals and vegetables spread over it.*

Note.—Before proceeding farther, the student will peruse with profit the Section on *Counting* and *Measuring* given in the Appendix.

Section 1. " *This earth is a globe or ball, nearly* 8000 *miles in diameter, of which the substance is drawn and held together in a rounded form by the mutual attraction of the component particles.*"

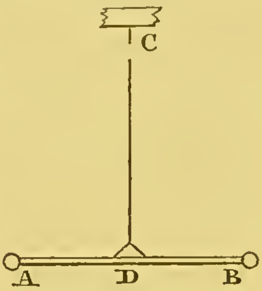
Very slowly have the facts been ascertained which prove the truth of these assertions. We proceed to state some in connected order.

1239. If water be allowed to escape through a small opening in the bottom of a glass tube, it appears as a mass rounded below, and increasing until its weight is greater than the attraction between it and the tube above. It then falls as a round drop, the mutual attraction of the particles being equal in all directions, producing such form. The successive drops are all of the same magnitude, and their number in a given time measures the quantity of liquid fallen.

1240. Dew accumulating on the leaves and stalks of plants takes similar globular form. Small quantities of quicksilver scattered on a level table exhibit it also very remarkably by their reflecting light strongly, and if several of these are gently pushed together they at once coalesce and form a larger globule flattened a little on the under side, which rests on the table. Still more complete instances of this kind are the millions of little perfect spheres of the shot-lead used by sportsmen. These were melted lead showered down from a height, and the drops were solidified by cooling during their descent. In small masses of liquid, the attraction of particles from their proximity is very strong, and is called cohesive attraction.

1241. But the general attraction, named, by its discoverer Newton, gravitation, acts at all distances. Thus, a plummet, or ball of lead, hanging by a thread, when it is over an extended plain has the thread pointing directly downwards, or at right angles to the surface of still water; but if the experiment be made near a steep mountain, the ball and string lean, or are attracted, towards that, and by delicate tests are found to be less attracted towards the mountain than towards the earth below it, owing to what is called its weight, only because the mountain is so much smaller than the earth, although its influence is increased by its centre being nearer.

1242. A strictly corresponding result is obtained in the experiment of balancing two small bells of any metal, A and B, at the end of an horizontal rod of wood, hanging from a lofty support C by a single wire CD. If, when the loaded wood is perfectly at rest, a heavy mass of any kind is brought near to the side of one of the balls, it attracts the ball, twisting the suspending wire in a degree which indicates the force operating. This arrangement constitutes a *torsion balance.*



It will be explained afterwards that the periodical rising of the great ocean-wave, called *the tide,* beneath, and following the apparent place of the moon when overhead, is an effect of the attraction of the moon acting on the moveable water beneath it. Newton discovered the law of gravitation, which rules this and other phenomena innumerable, while studying the motions of the moon in her orbit round the earth.

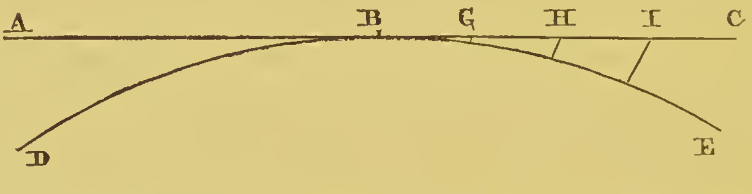
1243. The law is expressed in these words: "Every particle or mass of matter attracts, and is attracted by, every other particle, or mass, with force proportioned directly to the magnitude of the masses, and inversely to the square of the distances between them."

1244. It is the force of the earth's attraction which causes the descent of a clock-pendulum to the bottom of its arc, from which, by the momentum acquired during its fall, it ascends again to an equal height on the opposite side. It then falls again, and so continues to vibrate. If the force of gravitation were greater or less, the vibrations would be quicker or slower. A pendulum at the level of the sea is nearer to the centre of the earth than when high on a hill-side, and the vibrations are fewer as the elevation is greater, in accordance with the law above expressed.

1245. It was after Newton's great discovery of gravitation that men understood that the pressure of their feet on the ground, produced by what they call their weight, is really a mutual attraction between their bodies and the earth, somewhat like that between iron filings and the end of a magnet, around which the filings cling. The force of this attraction, like that of the magnet, bears a proportion to the distance. In consequence of such attraction a man, on whatever part of the globe he be placed, stands with his feet towards the centre, and the locality appears to him to be the top of the globe.

The facts above noted suggest the conclusion as probable that this earth is of globular form. The additional facts yet to be considered convert such probability into certainty.

1246. Canals for inland navigation are now common over the civilized world, and every intelligent constructor is aware that their bottom, in order that the depth of water in them shall be everywhere the same, must be made, not a straight surface represented by the line A B C, seen level at B, but as part of a hoop or curved surface D B E, sinking downward from the straight or tangent level A B C, taken at the point B, very nearly eight inches for the first mile from B.



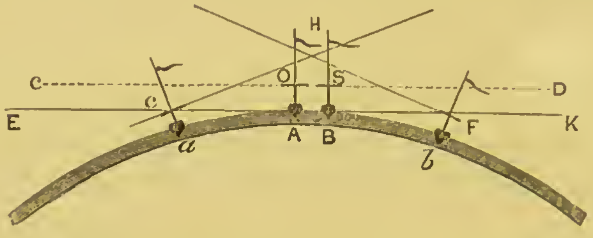
1247. And the important fact is to be remarked (more fully explained in the Appendix), that the sinking from the tangent line, at double distance from B, is not *twice* eight inches, as might be expected, but *four* times eight; at triple distance, is not three times, but nine times as much, and so on for other distances, as the squares. Thus, the distances in miles being 1, 2, 3, 4, &c.; the squares are 1, 4, 9, 16, &c.; and the inches of descent are 8, 32, 72, 128, &c. For greater distances the descent is calculated in the same way, and it is found that at a distance of 10 miles it is 66 feet, at 14 miles 150 feet, at 150 miles (the distance at which the Peak of Teneriffe comes into view over the watery horizon) the descent is 15·840 feet, or nearly 3 miles, the true height of that mountain.

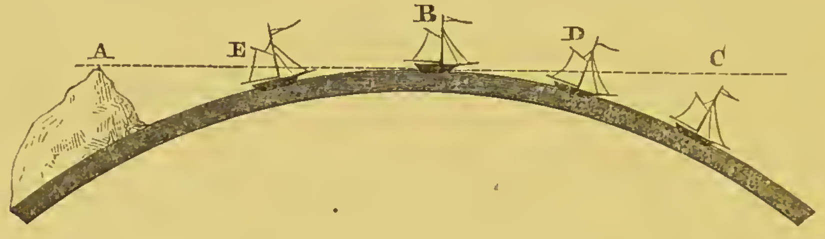
It is to be observed that the rule explained here for heights and distances tells also what breadth of sea is visible from any given elevation above its surface, whether from the mast of a ship or from the land.—The engravings given here greatly exaggerate some of the proportions to render the lessons more striking.

1248. A simple mode of proving the fact of this sinking down of the true level of a canal from the tangent or apparent level, and of ascertaining its amount is, to set up in the middle of a straight canal a row of poles, rising all ten or more feet above the surface of the water. If the row be quite straight, a person looking along with the naked eye, or with a telescope, from near one end, can see only the nearest pole, for it would hide all the others, because light moves in straight lines. But if on these poles cross-pieces are affixed at equal heights, say of five feet, above the water, and if the telescope, set level at that height, is then directed along the level, instead of the nearest cross-piece, hiding all the others, as is true of the vertical poles in a straight line, it leaves them all visible in a curve, like pins projecting sidewise from the rim of a wheel, and the cross-piece on the pole standing at the distance of one mile from the station B, would be found to appear just eight inches below the apparent straight level, as judged of by the telescope levelled at the station B. The cross-pieces more distant than one mile would be found to be lower by increasing differences, as seen in the figure at G H I, &c., and in the tabular statement given above.

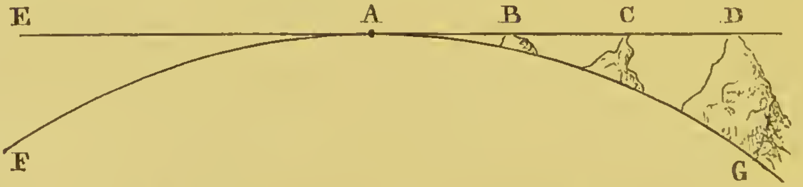
1249. In whatever part of the earth this experiment is made, the like results are obtained, proving the degree of convexity to be, in round numbers, the same everywhere, and, therefore, that the earth is really a sphere. A slight deviation to be afterwards explained, due to the rotation of the earth, confirms the general truth. Now a simple arithmetical computation tells that a dip of eight inches in the first mile belongs to a globe of very nearly 8,000 miles in diameter. There are other modes of extreme precision of measuring the dimensions of the earth, all accordant with that just described.

1250. It is the same kind of experiment modified, and yet more simple, when in winter the poles are set up on the frozen surface of a canal or a lake. It is still the same when, instead of fixed poles in the water, the masts of two similar boats are used, on which telescopes are fixed. Let A and B be two such boats on a straight canal. Telescopes O S on their masts, set level while near, would point to each other; but as the boats separated, would have their axes or lines of sight pointing gradually higher and higher as the distance increases, according to the law above explained. At the distance *a b*, the boats would have become what sailors call hull-down, or with the body of one vessel concealed from the view of persons on the deck of the other, and the telescopes could see over the convexity of the globe between them only the parts of the masts above that level.





1251. The adjoining sketch is of the same ship, viewed from the same cliff on the sea-shore A at different distances. The dotted line A B C is the line of sight touching the surface of the convex sea when the ship is at B, commanding only part of the rigging at D, and seeing nothing of the ship at C.



1252. There is an interesting case, which in many situations on earth offers itself to notice, namely, where a spectator at E, in looking along the apparent level-line at A, just sees the top of a hill at B, and of a second loftier summit at C, and of a third loftier still at D, apparently all on the same level. The summit

D might be one of the Andes, 25,000 feet high, and the others lower as less distant, according to the rule above explained; and in any such case the height being known, the distance is known, or the distance being known, the height is known, by computation.

1253. The surface of the convexity or bulge of the sea, existing between a spectator and a distant object, is called the water line or natural horizon. It is always of course beneath the tangent or apparent level, passing through the eye of the spectator, and the angle of depression is called the *dip of the horizon*, which is greater or less, according as the spectator is placed high or low above the level of the sea. For the use of mariners, books on navigation have a table, stating the amount of dip for different heights of the observer's eye.

The following facts illustrate, and are explained by what has now been said of the form of the earth.

1254. When two persons approach each other from opposite sides of a river to pass over a bridge, of which the general surface is part of a circle rising high in the middle between them, —as was true of many bridges in former times, each sees first only the hat and head of the other, and then gradually the whole person. After passing, they disappear from each other in the reverse way, the feet and lower parts of the body first, the upper part the last. So, on a much larger scale, two ships, approaching over the convex sea, exhibit to telescopes first their upper sails and rigging, and after they have passed each other, lose sight first of the lower parts. As they vanish, the sailors' phrases are that they are *hull-down*, or *half-mast-down*, and so forth.

1255. A ship departing directly out to sea is soon to persons near the shore, hull-down, and appears to have reached beyond a distinct wall of water (1257). A person at that time, on a height near the shore, as a lofty building, still sees the whole vessel.

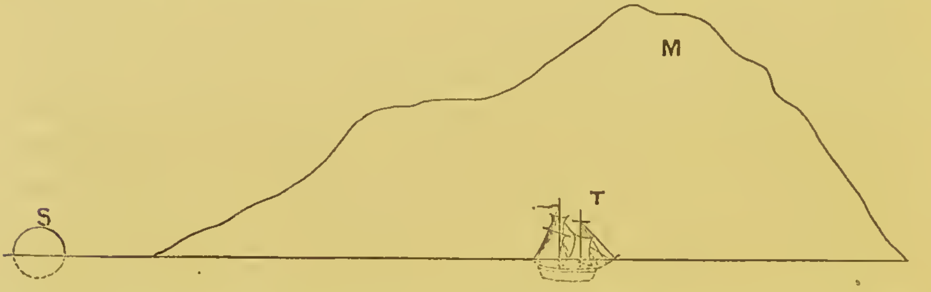
Ships at sea, which are hull-down to persons on the deck, are fully seen by the lookers-out near the mast head; and distant land may be seen from the mast-head over the bulge of the sea, where persons on deck see nothing.

1256. The extensive plains in America called *prairies* and *pampas*, which are nearly as level as the surface of the sea, exhibit the same phenomena of hiding by their bulge distant objects from persons travelling over them.

Rivers crossing such plains are not, as generally supposed, straight gently-inclined planes, but portions of hoops, of which the parts towards the mouth of the river are a little nearer to the centre of the earth than the parts behind. It seems strange until explained, that a ship may be seen hull-down though floating on a higher part of a great river.

1257. When the sun appears half set over the sea, it is the substance of the convex water which hides the half unseen from people on the low shore, for they have only to mount a little and they see all again.

1258. A ship near the centre of a scattered fleet may see the distant ships all round, beyond the water horizon, half concealed, as if to that extent submerged. This appearance is more striking where the ships have a background of high mountain beyond them. They then appear as if they were aground between the near water-horizon and the shore beyond.



1259. The sun sets entirely to people on a low plain, or on the sea-shore, long before the inhabitants of hills near have lost any of his beams. And the peaks of very elevated mountains are seen shining as brightly as the moon does after sunset so long as the sun's rays continue to reach them.

1260. Near the border line, between the enlightened and the shaded portions of the moon in her quarters, the telescope sees always a number of irregular luminous spots, as bright as any part of the shining surface. These are the summits of mountains receiving the slanting rays of the sun, while lower parts near are still in the shade.

It has seemed strange that after sunset the song of a lark, invisible from the earth, should still be heard by people below. The explanation is, that the blithe bird on the wing may still have sight of the sun, when from eyes below he has quite vanished.

1261. Aëronauts, who, in descending, reach the earth just after sunset, may see the sun again, and therefore can make an artificial sunrise by throwing out some ballast and so remounting into the air.

1262. If the inhabited earth had been a broad plane surface, as believed of old, beyond the edge of which the sun and stars in setting had to descend, sunset and sunrise would have happened to all the world at the same moment. But, in fact, when the sun sets over the sea, to people on one part of a coast, the telegraph from a part farther west can report that to them he is still at a considerable elevation; and in all parts of the earth he sets and rises just as much later as the place is farther west.

1263. A ball held in front of a fire is much heated in the middle part where the rays fall directly upon it, but less and less towards the sides, in exact proportion as the rays fall more obliquely. Nearly in such proportion are the climate and parts of the earth colder towards the poles than near the equator.

1264. Globular form in the earth is a natural consequence of general attraction of gravitation, for even if the earth had consisted originally of irregular solid masses, these, as happens to hard bricks piled on one another to a height, acting with their gravitating weight and pressure, would crush the portions below into fragments or powder, and the heap would subside. In a great mass of ordinary matter, a considerable deviation from the globular form necessarily causes these pressures to exist, until by subsidence the equilibrium of more rounded form is produced.

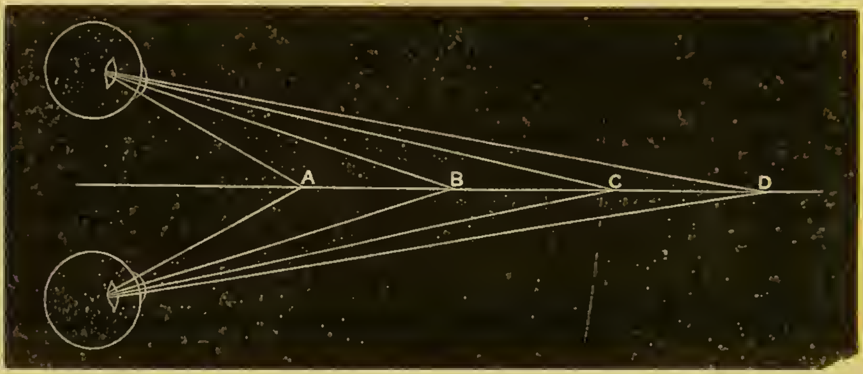
1265. In regard to the size of this globe, the perfect agreement of the log-books recording the progress made, day by day, by the innumerable ships which have now sailed round it, since Columbus taught the way, confirm the other more precise modes of measurement, which declare the size to be that of a diameter of eight thousand miles.

"*The Earth is distant from the moon, the nearest body to it, about thirty times its own breadth or diameter.*" (Read the Analysis, at page 647.)

1266. That the moon is nearer to this earth than any other of the bodies seen from the earth, is proved by the fact, that as it travels round the sky, wherever it is in the same line as other bodies and the earth, it hides them for a time. This fact attracts little notice, except when the body hidden is the sun, on the light and heat from which the well-being of the inhabitants of the earth depends. This occurrence, so awful to our forefathers, who did not understand it, is called the "eclipse of the sun."

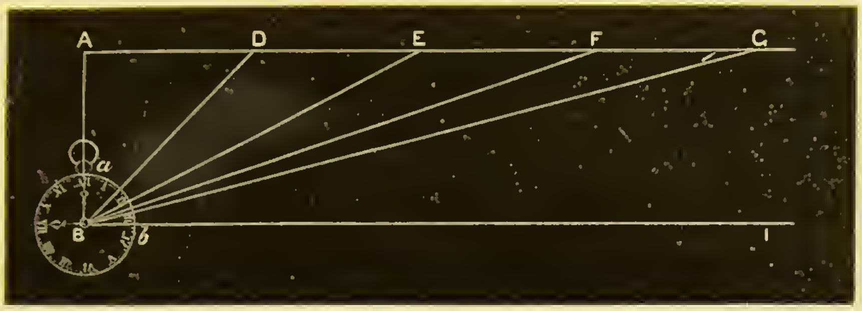
To persons of good understanding, but not yet instructed in the art of measuring, sketched in the Appendix to this volume, to measure the distance of an object which the observer can only look at, but cannot approach,—as in the case of a balloon in the air, or a cloud, or meteor, the moon, the sun, &c., appears an impossibility, yet human ingenuity has devised the means of effecting the object most satisfactorily.

1267. In the chapter on Optics, page 571, it was explained that in regard to objects comparatively near, persons judge of the distance by several means, but especially by the degree of convergence, or angular approach of the axes of the two eyes which have to meet at the object in order to see it distinctly. This is recalled in the adjoining diagram, where the small circles mark the eyeballs, from which lines going to A B C D, show different inclinations or convergence of the axes. The angle or corner formed at the meeting of the axes at A, is evidently greater than that at B, and still greater than that at C, &c. The person is conscious of the difference of effort required, at the different distances, to cause the axis to converge sufficiently, and that consciousness serves as a measure.



1268. Now to judge accurately by that angle of convergence, in regard to objects very distant, like the moon, sun, or a planet, men have contrived to employ, instead of the two eyes, two telescopes, placed at distant stations, or one telescope used successively in two stations, and then by fit means to measure most accurately the angles of direction of the telescopes whose axes meet at the object.

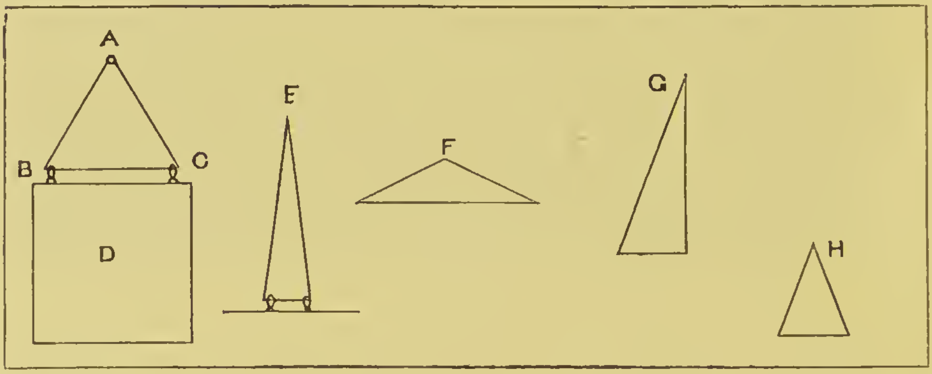
1269. The fixed relation of such angles and distances may be rendered intelligible to commencing students, by the simple case now to be described. Let the lines A G and B I represent



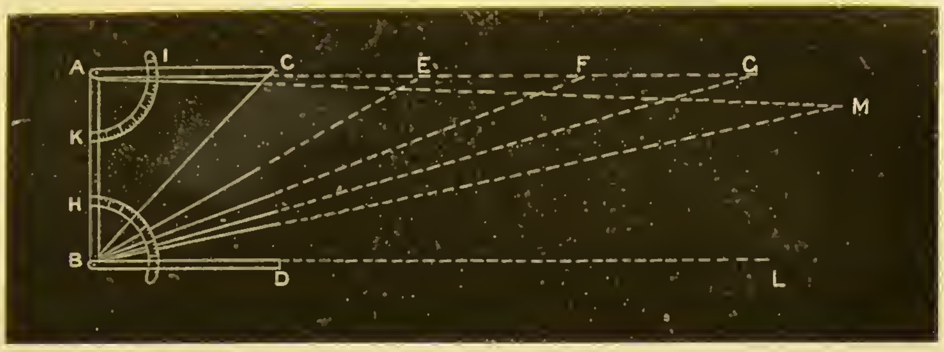
parts of the parallel sides of a long straight street, with a row of lamp-posts in it, A D E F G, about the width of the street apart. Let a pocket-watch then, with large dial face, be placed on a table at B, directly opposite to the lamp-post A, where the crossing line A B forms a square corner or right-angle with the line A G lying along the street. Let the minute-hand of the watch point to 12 o'clock, and to an attendant standing at the lamp-post A. If the attendant then move to the post D, and the minute-hand be turned to follow him, the eye of an observer, through a small telescope, placed in the direction of the hand of the watch, will see the attendant in the direction B D, which may be represented by a thread stretched from B to D. That thread will cross or cut the divided circumference *a b* of the watch then serving as an angle-measure, instead of a time-measure, at a certain angle (here of 45°). The attendant continuing to advance, would reach the posts, E F G, &c., in succession, and would be seen along the lines B E, B F, B G, &c., cutting the curve *a b*, at different points nearer and nearer to *b*, and forming angles of less and less magnitude, with the line B I. This process might be continued until the eye could no longer distinguish the more distant lamp-posts, nor estimate aright the lessening portions cut off on the divided curve *a b*. But so long as these could be distinguished, every distance among the posts would form its own distinct angle, and he who could read the angle would always know the corresponding distance of the lamps on the prolonged line A G. By such an experimental process, and still more accurately by easy computation, a table of tangents can be constructed showing the distances and angles, which have fixed relations or correspondence. Such tables are contained in elementary books.

A common watch is here referred to as an angle-measure, because it is so well or familiarly known, and because its hand, in moving forward does so evidently divide the space around the axle into all possible angles. The instruments actually used for measuring angles have always a metallic circle, or portion of a circle, accurately divided into equal degrees, or parts of a degree, over which an index travels. So perfect now is the manufacture of such instruments, that they enable the eye, when aided by a microscope, to distinguish the twenty-thousandth part of the circumference of a circle.

1270. It is a very important fact that under certain circumstances, by measuring the angle formed where two straight lines meet, the length of one of them pointing to a distant visible object can be accurately known. This will be explained more fully in the *Appendix;* but we may at once state that it depends on the remarkable properties of the figure called a *triangle,* which consists essentially of three sides, so joined as to form three corners, or angles. It is roughly exhibited when a cord A B C is employed to support a picture-frame D on a wall, the cord passing through two rings B and C on the frame, and resting on a nail at A on the wall; or, when a piece of thread of any length, having its ends joined to form a loop, is laid on a flat table and is opened out into the form of any triangle by outward pressure made at any three points.

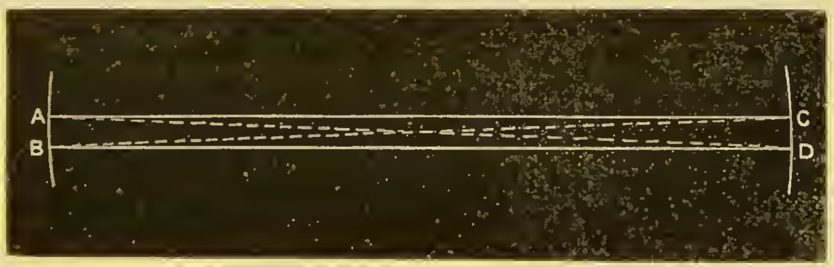


The properties referred to are, first, that whatever the shapes of triangles be, as here of A E F G H, the sum of the three angles of any one is always exactly equal to two square corners, or right angles, so that when any two of the angles are known, the third also is known; and second, that of the six particulars named of sides and angles, if any three, one of these being a side, are known, all the six are knowable either by simple computation or by drawing the figure of a convenient size on some flat surface.



1271. The simple arrangement here sketched further illustrates this subject. A B is a flat ruler or rod, in wood or metal, about a yard long. A C and B D are similar rods of any length, hinged moveably to the ends A and B. The rod A B, called the base of the figure, has affixed at H and K two arcs, or portions of circles, H I and K I divided into degrees, by which the angles formed at A and B by the moveable arms and the base can be measured. Laying this on a table, and causing the moveable arms to point to any object, the visual rays, indicated here by dotted lines, will meet at the object, as M, to form an angle which by the tables spoken of, or by computation, tells the distance of the object. By such a rude instrument, a person without moving from his chair can judge of the distance of any object within view, in a room, or garden, or field.

1272. The angle to be determined in all such cases is called the angle of parallax, the reason of which appellation is thus to be explained. The figure A B C D shown here is called a parallelogram, because its opposite sides are parallel to each other; that is, are at the same distance apart wherever a directly transverse or cross measure is taken, and therefore, however far prolonged in either way, they would never meet. But a line



called a diagonal, drawn between opposite corners of the parallelogram, as from B to C, or from A to D, is not *parallel* to the sides, but has a *changed bearing* called *parallax*, and the sharp angle formed at the corners of the parallelogram between the diagonal and the side is the angle of parallax.

If an observer at A look through a telescope with graduated arc, towards an object at C, bearing directly east from him (or in any other exactly ascertained direction), and if he then shift his station to a certain known distance B, at right angles to the line A C, and he again look towards the object C, he finds its bearing changed from being directly east to the other line B C, inclining north of east by the sharp angle D B C at the corner B. This is called the angle of parallax. Whatever part of a whole circle that angle is, just such part of the circumference of a circle which has C for its centre, and the distance C A for its radius or semidiameter, is the distance A B which has been measured, and from that part being known the whole circumference is known, and consequently, the semidiameter of the circle which was the distance sought.

1273. In regard to the distance of the moon from the earth, the shape and size of the earth being now well known, the distance of any two remarkable places upon it is also known, and the straight line of distance between any two such places may serve as a base line for measurement. Places which have so served are the two observatories of Greenwich and the Cape of Good Hope, at which, angles can be measured which will declare the angle at the summit of the figure M, where the moon is supposed to be. A still simpler mode of ascertaining the angle of this parallax is to measure the apparent angular distances, as seen at the same moment from these places, between the moon and a known fixed star. (In these measurings many details have to be attended to which are not noticed here.) The distance of the moon from this earth is by these means ascertained to be 240,000 miles nearly, or thirty times the diameter of the earth.—Knowing the distance in such a case, and the apparent diameter, because the moon, like all the other heavenly bodies, is globular, the size of the moon can be computed, as described in Optics, 1077. The diameter is thus estimated to be 2160 miles, rather more than a fourth part of the diameter of the earth: the bulk of the moon is nearly a fiftieth part of that of the earth. This vast magnitude explains the fact so long the wonder of our forefathers, who did not understand it, of how the influence of the moon might suffice to lift the tides of the ocean to a height of several feet above the usual sea-level.

By kindred means to those above described astronomers have ascertained the distance of the sun. It is four hundred times greater than that of the moon, and the bulk is more than a million times greater than that of this earth. The greater difficulties of obtaining the measurements for the sun are treated of in coming pages. The distances and magnitudes of the heavenly bodies are so vast, that the human mind has difficulty to conceive them; and the angle of parallax, which measures them becomes so small, that instruments of extreme delicacy, and the aid of strong microscopes to read the indications, are required for the purpose. Supposing the procedure to be typified in Fig. 1271, the lines A G and B L, or those marked A M and B M, instead of being two converging sides of a remote angle, become very nearly parallel. The angle of parallax of the sun is only about 8½ seconds, less than the 50,000th part of a circle, and that of the nearest fixed star is barely one second (1″), proving that with respect to the stars, we can say that the nearest is 1000 times farther off than the sun, and the more remote, vastly beyond that. The fact that many of them, notwithstanding this, can send so much light as they do to this earth, is held to prove that many of them are at least equal in size to our sun.

Section 2. "*The earth is rotating, or turning about its centre, once in twenty-four hours, and by being in view of the sun has the changes or alternation of day and night.*" (Read the whole Analysis, page 647.)

After the invention of telescopes and their mountings which enable human sight to penetrate far into space and to see many other globes larger than this earth, which are rotating and revolving, men could not doubt of the possibility of this earth's rotation, and they were prepared to weigh the evidences adduced to prove it.

1274. If men of old, because they knew not the fact of universal gravitation, were far from suspecting that the earth was a great ball balanced in free space, as little could they conceive how the parts of a ball could hang together, or how inhabitants could dwell on it elsewhere than on what was deemed the top, or upper part of it, still less did they suspect that the vast mass was in rapid motion. It was evident to them, however, that great and swift motions were going on in the universe; for the sun, moon, and stars appeared every twenty-four hours to rise, in the east, beyond countries known to be thousands of miles distant, eastward, and after traversing the sky, to set, beyond countries known to be as far to the west. The natural conclusion was that the motion was in bodies very much smaller than the earth. They were led to the same conclusion by the common belief that persons could not be in very rapid motion without danger, and without having a distinct feeling which informed them of the fact.

Gradually, however, after Newton's discovery of *gravitation* and great improvements made in the telescope, assurance came to all who studied, that the heavenly bodies visible in our sky were prodigiously more distant and of greater size than had been suspected of old, and that many of them were in rapid motion. Proofs were obtained also that very swift motion was not at all hurtful to the human constitution, and that, if perfectly smooth and uniform, it was not even felt.

1275. Aëronauts in the car of their balloon, when moving a hundred miles an hour, have no sensation of being in motion, and if surrounded by a cloud, which prevents them from seeing objects around them, they cannot know in what direction they are moving. The same is true of persons in ships drifting along in sea currents out of sight of land, as frequent disasters have proved. A person sitting in the cabin of a ship at anchor, if occupied in reading or writing while the ship is swinging round with the turn of tide, has no perception of the change. A man seated in a chair suspended by a rope from a high ceiling, if his eyes are covered, has no sense of any turning motion softly given to his seat. A person in a small floating boat or tub, surrounded by a floating screen which hides from him all beyond it, cannot know, when any gentle motion is produced, whether it is in his boat, or in the screen, or partly in both. Uniform motion of this globe then, however rapid, would not be perceived by the inhabitants. The motions of walking, riding, being driven in a carriage over a rough road, being tossed in a boat on a rough sea, and so forth, are examples of the opposite kind.

There soon remained, therefore, no doubt that the momentous changes of day and night and many kindred phenomena, attributed of old to motions among the heavenly bodies were really due to motions in the earth itself. The subject is interestingly considered in the following manner.

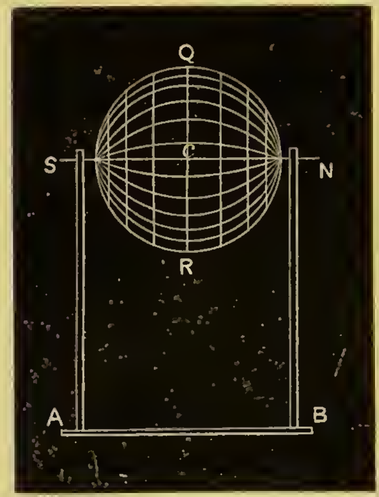
1276. Let a person just after the setting of the sun, of which the intense brilliancy during the day prevents all smaller lights from being seen, ascend to the house-top or other eminence which commands an unobstructed view of the horizon around, and let him there contemplate at leisure the nocturnal sky. He may in the morning have seen the sun appear to rise in the east, and gradually move across the sky to set or disappear in the west. As the setting sun's light fades, he finds himself apparently in the centre of a stupendous vault or concave half globe, thickly studded with luminous objects, which he has been taught to call stars. Among these he perceives as little order of arrangement as among the first drops of rain falling on a white pavement, but soon, individual stars are distinguished by their greater brilliancy, and others by belonging to certain groups, which bear some resemblance to familiar forms on earth, as of square, cross, triangle, and so forth. He then soon perceives that all the stars have a movement towards the west, like that of the sun during the day, and that those near the western horizon are setting or disappearing, to follow the sun, while others are rising into view in the east, and maintaining, undiminished, the splendour of the spectacle. In the course of the night, if the observer watch to the end, he has seen not only that starry half-globe or concave, which was overhead when the sun disappeared, but also the whole of another half, which, as the night advances, gradually takes the place of the first. With the sun's light returning and producing the dawn of next day, the feebler lights of the stars are first dim, and soon cease to be at all perceived by the naked eye; but a good telescope can see and follow them moving on all through the day, just as the naked eye did during the night; and those subsequently rising in the east are found to be those which twelve hours before set after the sun in the west. The observer thus finds that he has seen the whole of the surrounding firmament in which the world exists, revolving like the continuous interior of a great wheel. The stars which rise and set nearly with the sun are, for the time, less conspicuous than the others, owing to his overpowering light; but when the sun gradually changes his place among them during his annual circuit, all, in their turn, are similarly dim or bright.

Now for thousands of years men have been watching the appearances of the stars, and observing that their relative positions have remained sensibly unchanged, have called them the *fixed stars*, to distinguish them from a small number, which seem to move about among the others as the sun does, and are called *planets* (from the Greek word *planao*, to wander).

Of fixed stars the naked eye, in clear skies, can count nearly three thousand. Telescopes show very many more. They have been divided into classes, according to their brilliancy. Of the first class, about twenty-four are counted and named, of the second, about fifty, and so on.

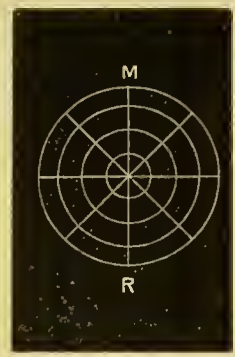
Distinguishable groups of stars are called *constellations*, and have had names given to them from fanciful resemblances in form to earthly objects. Twelve of these lying in the apparent annual path of the sun are called the *signs of the zodiac* (from *zoe*, life), as the Ram, Bull, Twins, Lion, &c.

1277. The spectacle of the nocturnal sky above described is rendered much more interesting by having at hand a globe, formed of wire, like a bird-cage, as here represented, with a spindle N S through its centre C, on which it turns. One end of the spindle N is to be directed to the north pole of the sky, and the other end S to the south. At places on or near the equator, as in our colony of Sincapore, in the Strait of Malacca, the spindle appears to the inhabitants to be horizontal, as here shown from N to S. A person sitting near the table which supports this globe, so as to be able to look through a small ring at its centre C, towards every star above the horizon, may attach in some convenient way, on the surface of the globe at the point which is in visual contact with the star, a small glass bead to represent it. He may then maintain such bead in contact with the star, by gradually turning the globe round as the star seems to travel westward towards the setting; and in the mean time he may employ himself in affixing other beads to represent the other most conspicuous stars then seen. These representatives of the star will set with them, by sinking under the level of the spindle S N, which indicates the level of the horizon. During one night, thus, a person watching until dawn of the new day, may complete an interesting model of the whole sky around this earth, as existing both above and below the horizon,



showing its most conspicuous stars in their true relative positions. In succeeding nights he may render the model more complete by adding other stars of inferior magnitude. Such a globe may be connected with a common clock, so as to turn round its axis once in twenty-four hours, and it will then exhibit uninterruptedly the true changing places of all the stars marked upon it, whether they are above the horizon or below, and it will point through the day to the parts of the sky where the stars, although unseen then by the naked eye, are to be seen through a telescope properly directed.

1278. While the figure 1277, half-covered by a card up to the axis exhibits the apparent motions of the sun, moon, and stars, all vertical, as seen by persons near the equator, the adjoining figure half-covered indicates the apparent motions, all level, which are seen near the poles. The axle of the globe, when similarly half-covered and placed obliquely, pictures the appearance at latitudes intermediate between the equator and poles.



Such a globe of wire with beads is a rough model of the so-called Celestial Globe, now part of the common furniture of our libraries. It has the advantage, by being transparent, to show both sides of the globe at the same time, and to allow useful comparisons to be made.

1279. The globe of wire, made like a bird-cage, leads the spectator to appreciate at once the importance of being able to give a clear name or designation to every part of the surface of a globe, distinguishing it from every other part. When on a chess-board a square is said to be in some certain row from the top, and some certain row from either side, it cannot be mistaken for any other square. So on a globe; if a spindle pass through its centre, circles of wire may be fixed round it, at equal distances from the ends of the spindle (called poles, from the Greek *poleo,* to turn), and they may be called circles of breadth or latitude; then other circles or lines of wire may be placed across these, cutting the equator at equal distances from one another, and reaching from pole to pole. These may be called circles of longitude. If all these circles have on them divisions into equal parts, all numbered, every spot or point on the surface of the globe will have its own latitude and longitude, perfectly distinguishing it from every other.

1280. A globe formed of white marble or other such material, if at rest, has no mark upon it to distinguish one part from another; but, if it be caused to rotate or whirl, every part instantly acquires certain peculiarities of motion, which clearly distinguish it. If a globe suspended by a twisted cord have small spots of any kind on its surface, as of ink spattered upon it, the spot to which the cord happens to be attached will appear to be at rest, as a pole of rotation, and every other spot will be describing a circle of latitude round the pole, which circle will be larger as it is further from the pole, until the equator, or the middle circle equally distant from both poles, is reached. A pen or pencil held to touch the turning globe at any spot, would mark a circle of latitude there. If lines were then drawn directly from pole to pole across the equator at equal lateral distances, they would form lines of longitude.

1281. A rotation like that of the spotted globe described, hanging by an untwisting cord, is given to any globe immersed in water so as just to float, if an oblique push or impulse of any kind be given to it. However the rotatory motion of the earth first began, when once established, it imparted to the earth all the valuable characteristics above described.

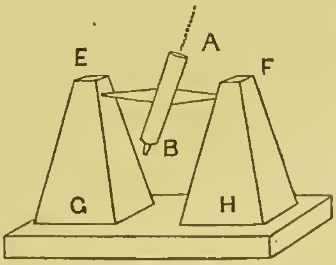
1282. It was explained in Art. 95, that any motion once given to a body never varies in speed or direction, but in exact proportion to some new force brought to act upon it. The rotation of this earth, therefore, and the direction or parallelism of the axis of rotation must continue without change, so long as the general laws of motion and force remain the same.

1283. It is readily perceived that the appearances of motion presented to the common eye among the heavenly bodies around the earth would be exactly the same, whether the bodies revolved round the earth as a centre, or the earth rotated as a central mass within a firmament at rest. It follows, therefore, that there are everywhere points or situations exactly corresponding in the starry concave above, and on the globular earth below. There must be in each apparently fixed points, to be called poles, round which every other point will seem to revolve, and there must be perfect correspondence between what are called the latitudes and longitudes below, and positions in the sky above. It is thus that a mariner bound to a small island like St. Helena, situated in the middle of a broad ocean, and which he cannot see until he arrives close to it, keeps his eye on the part of the sky which he knows to have the latitude of the island, and sails until he brings that part nearly over his head.

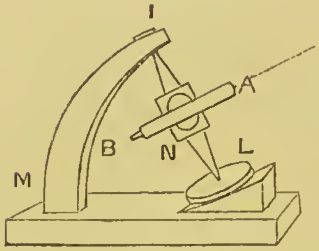
1284. Inspection of the globe sketched in Art. 1277, or of the common celestial globe placed in libraries explains readily the following terms:—*Poles* of the globe,—the *equator*,—*latitudes* and *longitudes*,—the *zenith* or summit of the sky over the head of an observer,—the *nadir*, a corresponding point directly below,—the *azimuth* of a visible object, or the relation of its bearing to the *cardinal points* of the compass, *north*, *south*, *&c.*,—the *horizon* or bounding level line on which the concave sky seems to rest.

1285. The business of the astronomer is chiefly to study and measure the positions and motions among the heavenly bodies, in relation to the poles, horizon, &c., as viewed from this earth, which is itself constantly in motion. By the apparent places of the heavenly bodies so observed, he learns the true places and motions, and can foretell much of what is to happen in future time.

1286. A perfectly constructed globe of metallic circles, all accurately graduated or divided into the usual degrees, minutes, and seconds, with a good telescope at its centre, turning in any direction, the whole being firmly supported on a suitable frame, would enable an observer to make most of the measures which the astronomer desires to make, and might be called a small portable observatory. So delicate, however, and requiring such extreme precision, are many of the observations to be made, that it has been found necessary, instead of many small elements joined together, to have large instruments placed apart. A fit building erected in a suitable locality, furnished with such instruments, is called an *Astronomical Observatory*.



1287. The chief instruments in an observatory are, the large telescopes with graduated circles, and the time-keepers. A good telescope can gather a thousand times more light from a distant object to form its image on the retina, than can enter the pupil of a naked eye. In the observatory are to be observed, 1st, the *transit instrument*, of which an outline is here given—a powerful telescope A B, turning on a level axle, firmly supported at E and F, lying directly east and west, which causes the telescope to sweep along the meridian line from the south point to the zenith and beyond. Through this is watched the instant of a heavenly body's passing the meridian line. The field of view of the telescope is crossed by several vertical lines, and the instant being noted of the star passing each of these, the average of all gives the exact time. 2nd, the *equatorial telescope*, here sketched. The telescope A B is supported on an axis which is made parallel to that of the earth, so that as the earth turns, the telescope having been pointed to any star or other object, follows that along its circuit. 3rd. the *mural telescope*, with large graduated circle. It has its axle fixed in the firm wall. It ascertains altitudes and polar distances very accurately. 4th. the *observatory clocks*, showing both sidereal and solar time.



Further details respecting the observatory are not given here, the object of the book being, not to train assistants for an observatory, but to explain to general students the principles on which the astronomer's proceedings are founded.

1288. One matter of importance has as yet to be mentioned, which occasions much trouble to astronomers, namely, that the rays of light which in empty space move straightly, do not so move when passing through the transparent medium of atmospheric air. They are then more or less bent or refracted according to the accidental temperature, moisture, density, &c., of the air at the time. Allowance has to be made for refraction, as explained in Optics, Art. 1026. In many astronomical observations, such as those made to determine the distance of the sun, a single second of an angular degree is an important quantity.

Among the general considerations bearing on the question of the earth's constant rotation on its axis may be mentioned the fact that all the other planetary bodies visible in the sky to our telescopes have such rotatory motion, and even the sun himself is seen so to turn once in twenty-five days six hours. Spots, which are frequently visible on his surface, prove this.

There are some very direct proofs of the rotation of the earth still to be mentioned.

1289. As a ball of soft clay placed on the centre of a potter's table or wheel (which rests on a turning spindle), bulges out at its middle, or equator, because of the greater centrifugal force there than elsewhere; so is this earth found, by accurate measurement, to bulge out at its equator nearly seventeen miles farther than near the poles, in exact accordance with the laws of central forces, treated of from Articles 115 to 138, which the reader should now again peruse as an important part of the present chapter.

1290. For the same reason a pendulum, of whatever length, vibrates more slowly near the equator than near the poles, because its weight near the equator is partially counteracted by the centrifugal force.

1291. A strikingly ingenious and beautiful experiment in proof was devised a few years ago by M. Foucault, of the French Academy, as follows. If a pendulum is caused to swing, it performs its motion in one direction or plane, as from north to south, and will not deviate from that plane unless urged by some new force. Accordingly, a pendulum hung from a support over the pole of a library globe set with its spindle vertical, will not be influenced by the turning of the globe beneath it, and will therefore show how far and how fast the globe may be made to turn under it. Similarly, a long pendulum, caused to vibrate from a fixed support over the centre of a large clock-dial laid on the ground near a pole of this earth, continues to move in the same plane, while the earth turns, and the line of the pendulum's motion continuing the same while the earth turns indicates the fact, and the rate of the earth's rotation. If the experiment were made exactly at the pole, the apparent motion would be as rapid as that of the hand of a sidereal clock. At different distances from the pole it is proportionally less rapid.

1292. A ball of metal suspended like a plummet from a point in a lofty ceiling will hang over a point in the floor which is directly beneath the point of suspension; but if the ball be allowed to fall freely from the point of suspension it will reach the floor considerably to the eastward of a mark on the pavement beneath the plummet. The reason is that the surface of the earth is rotating eastward, and as, in a turning wheel, parts distant from the centre have swifter motion than parts near to it, a body let fall from aloft will reach the floor in advance of where it would hang as a plummet.

1293. Many of the most remarkable motions observed on the surface of the earth, as the winds in the atmosphere and certain great currents in the seas, have their force and direction much influenced by the whirling of the earth. Explanations are given from page 278 to 283. The phenomena of the trade-winds, hurricanes, cyclones, &c., and of such movements in the ocean as the warm Gulf Stream which sets across the Atlantic from the Mexican Gulf to the western shores of Europe, were little understood until within the last fifty years, and the value of the new knowledge may be judged of by the vast improvements in navigation, made within that time.

§ 3. "*This earth travels in an orbit round the vastly greater globe, the sun, once in* 365 *days and a fraction, being held within its orbit by the attraction of the sun, as a stone in a sling is held by the strength of the cord.*" (Read the Outline, page 647.)

The reader, when acquainted with the great facts of the spherical form of the earth, and its diurnal rotation which causes the alternation of day and night, is prepared to understand the additional motion of its annual revolution round the sun, which causes the phenomena of the year with its seasons.

1294. If a lamp stand on a table in the middle of a room, at the height of the eye of a person walking round the table, that motion will bring the lamp into apparent visual contact in succession with the different objects on the wall at the same level. Or, if the person become stationary in the middle of the room, and the lamp be carried round, the same result follows. It would be a case still more closely resembling the facts of astronomy, if a great lamp stood in the middle of a racecourse in a dark night, when nothing could be seen but the living lights in the country around. A spectator carried round the course would see the central lamp coming into contact with the other lights in turn. The great lamp, in such a case, would represent the sun, and the smaller lights the more distant stars. Until men obtained the irresistible proofs that the earth on which they live is itself in rapid motion, they naturally concluded that all the apparent motions were in the distant objects.

It was evident that either the sun must be revolving round the earth, or the earth must be revolving round the sun, but either supposition seemed irreconcileable with other parts of man's knowledge. For instance, if the earth was supposed to be fixed in space, they could not imagine by what means it was so fixed, and they had to believe that the stars which they called fixed were retained in their relative positions by connection with a vast transparent or crystalline concave, which had a constant revolving motion.—At last the great Newton came, and was able to demonstrate that there was no material connection between the myriads of moving bodies visible in the sky, but that they were all maintained in constant movement and harmonious order under the balancing influences of a universal mutual attraction, which he called *Gravitation,* and of a centrifugal force generated by forward motion.

1295. The great laws of motion and force, which work such perfect harmony in the living universe, are thus briefly expressed:—

> 1. Straight uniform motion once produced in any body is as naturally permanent as the state of rest, so that no change of speed or of direction is effected, but in proportion to a new force applied.
> 2. A new force, applied directly across the course of an existing motion, changes the direction of that, but does not at all lessen the onward speed, and, when just balanced by the centrifugal tendency, produces a curved or orbitual motion, which will not lessen or cease of itself in any length of time.

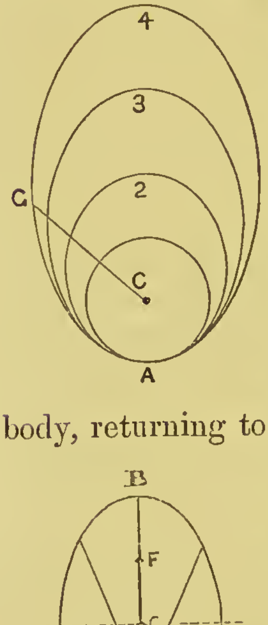
1296. Detailed explanation of these laws is given from pages 46 to 59, which should be studied again as part of the present chapter. The truth of the second law is not so readily apprehended as that of the first, and is here reconsidered.

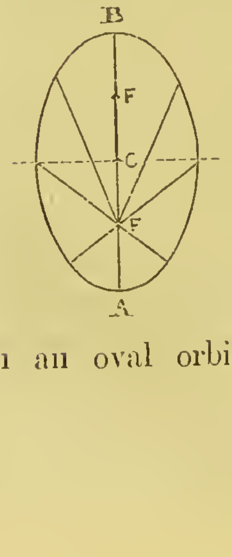
Let a boat be carried east from *b* to *e* (fig. at page 55) in a tidal current at the rate of a mile in ten minutes, and at the same time let it be driven by a wind blowing directly across, from *b* to *s*, south, at the same rate; it would move in a middle course, *b a*, south-east, and would arrive at *a* in ten minutes, as it would have arrived at *e* or *s* if only one force had been acting. It is evident that in such a case there is no loss either of the onward motion or of the transverse motion. Similarly it is found that if a cannon-ball be shot horizontally from the top of a wall, its directly downward motion by force of gravitation towards the earth does not retard the progressive motion which is overcoming the resistance of the air, and the progressive motion does not affect the downward motion, for a ball simply dropped from the height of the cannon's mouth reaches the ground at the same instant as the ball projected by the gunpowder.

1297. These facts furnish the explanation of why a planet moving in a circular orbit round a central sun, and powerfully attracted by the sun is drawn inwards towards the centre, or away at every point, from the straight line called the tangent to the orbit, yet it loses nothing of its onward motion. The centripetal force is always acting directly *across* the forward course, but is in no degree opposed to it.

1298. The two equal forces balanced as above described are called the centrifugal (*centre-flying*) and the centripetal (*centre-seeking*) forces, and when they are exactly equal they produce an orbit exactly circular, as that marked C. A student might at first suppose that any inequality occurring between the two forces would destroy the orbitual motion altogether—an excess of the one projecting the planet into boundless space, and excess of the other drawing it down to be absorbed into the central mass, but neither of these events does take place—for—

1299. If, when the revolving body arrives at A, an additional forward impulse towards G were given, instead of driving the planet away altogether into boundless space, like a stone leaving a sling, there would be merely the conversion of a circular orbit into an oval, or elliptical one, more or less elongated according to the strength of the impulse. It is readily conceived that immediately after the new impulse, the planet having greater centrifugal force, would take a course such as shown in 2, 3, or 4, external to the circular curve C, but evidently at the same time, the attraction of the central mass in C would no longer be acting directly across the orbit, but as seen in the figure at G, would be an oblique force, pulling back or slackening the speed of the planet, and, therefore, lessening gradually its centrifugal force. The inward or centripetal bending would consequently be less opposed in the upper part of the oval, and the planet would soon become as a falling body, returning to A with quickening speed, to recommence the upward journey towards G in the ellipse. The speed lost in the ascent would be just balanced by the equal speed recovered in the fall (see the Art. 179), and although the velocity of the motion would be constantly varying, the time of performing the whole round would remain the same. One of the unsuspected facts soon discovered was that a body revolving under the force of gravitation, in an oval orbit, does not keep the great interior mass in





the centre of the orbit, as at C, but in one of the *foci* of the ellipse, as F or F.

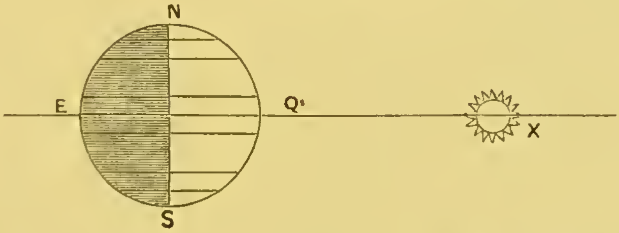
1300. It was the marvellous penetration or sagacity of the mind of Isaac Newton which first saw clearly the nature of the forces which regulate all planetary motions,—as explained by him in his immortal work "*Philosophiæ Naturalis Principia Mathematica.*" One of the rewards of those who pursue their mathematical studies beyond the simpler elements is to be able to read and fully understand that extraordinary work. The estimation in which the world has held that work was aptly expressed in the two lines of Pope :—

"Nature and Nature's laws lay hid in night;
God said, 'Let Newton be,' and all was light.'

"*An inclination of the Axis of rotation of the Earth to the plane of its revolution round the sun is the cause of the* CHANGE OF SEASONS." (Read the Outline, page 647.)

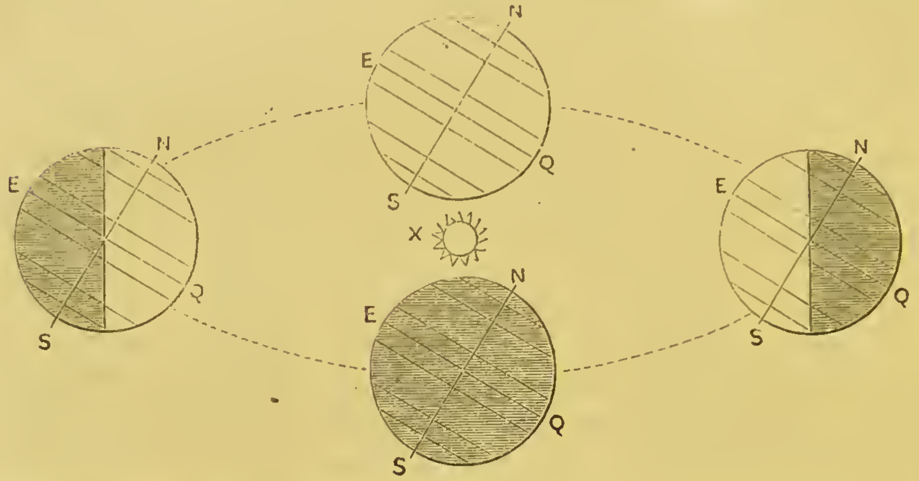
Changes of Season.

1301. There is one circumstance connected with the revolution of the earth round the sun which is of great importance to the inhabitants, although it might at first appear to be a matter of mere accident and indifference—namely, that the axis of rotation of the earth does not stand at right angles to the plane of its orbit round the sun. Let X represent the sun, supposed to be at a great distance (although here, for want of room, placed near), and let E N Q S represent the earth, N being the north and S the south pole of the axis, standing at right angles to E Q, the line of the equator and of the earth's orbit. Evidently if the sun were from the earth in the direction E Q X, his rays of light and heat would always fall directly on the equator, and the sun would always appear to be directly over the equator. The nights and days would always be of the same length of twelve hours, as indicated in this figure by the perfect correspondence of the enlightened and the shaded halves of the



globe, and there could be no considerable change of temperature anywhere throughout the year.

1302. But the axis of rotation N S is not perpendicular to the plane of the orbit. As represented in this figure, the north pole N leans 23½° towards that plane, and in the summer position for Europe, indicated here on the left hand, it is seen that the northern part of the globe is receiving much more sunshine than in the winter position, shown on the right hand. The upper and lower globes in the middle show that at half way between summer and winter, although the axis of rotation is oblique, the northern and southern halves of the earth share equally the light and shade. This figure exhibits also where upon earth the days and nights are longer than twelve hours and where shorter.



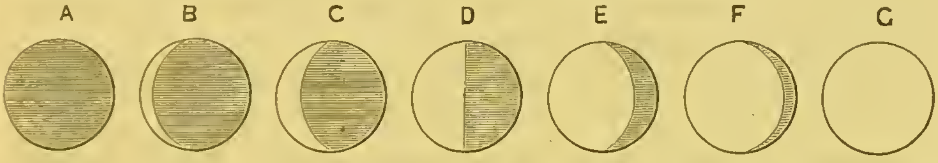
1303. It might be expected that there would be a tendency in the rotating globe to change or rectify its position to that shown in Art. 1301, but there is no such tendency. There are a few slight and slow changes occurring in the direction of the earth's axis to be explained under the heads of precession of the equinoxes and nutation; but they are of the nature of oscillating motions, which compensate or rectify themselves after a certain time.

> "*The Earth is accompanied by a smaller globe, the Moon, which revolves about it, as it revolves about the Sun.*" (Read the Outline, page 647.)

The explanation given of the balancing forces which maintain the earth unerringly in its orbitual path round the sun applies also to the case of the moon revolving round the earth.

1304. Of the many bodies in our solar system, the sun is the only one which is self-luminous. The others, including the moon and all the planets, can affect our sense of sight only when reflecting part of the light which falls on them from the sun—just as is true of any common object in a landscape which in the darkness of night is quite invisible, but in the sunshine is beautifully bright.

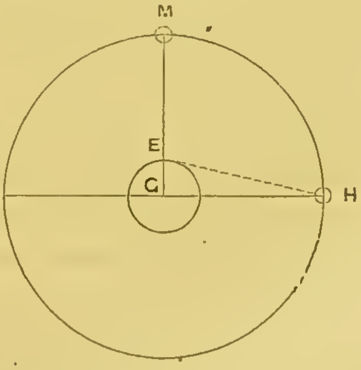
1305. It was the common belief of old that the moon also was self-luminous, a misconception which rendered the phenomena of the slender new moon gradually growing into the half-moon and full-moon, with the subsequent decline, so mysterious or inexplicable to them. No one then thought of making the experiment of suspending a ball near to a strong lamp in the external air of a dark night, and then walking round it to see strikingly exhibited all the phases of the wondrous moon. The appearances are recalled by the adjoining diagram.



Nearly the same result is obtained by painting one half of a globe white and the other half black, and then suspending it so as to cause it to rotate slowly before the eyes.

1306. To be told that the moon, which a child or uneducated person judges to be of about one foot in diameter, is in truth more than a fourth part as broad as this earth, might stagger the belief of any commencing student, but the evidences of the truth are many and irresistible.

Let the circle C represent the earth, M the moon over the head of a person at E, and M H part of the apparent path of the moon travelling round the earth, always at nearly the same distance from the centre of the earth C. It is evident that the moon, when at M, is nearer to a spectator on the earth at E by half the diameter of the earth—4000 miles — than when she is setting beyond the horizon at H. According to the law of optics, that an object appears smaller in proportion as it is further away, the moon



when at H should appear smaller to the spectator at E than when at M. Now, when measured by a fit instrument it does appear smaller by just one-sixtieth part of its diameter. This proves, therefore, that 4000 miles is the sixtieth part of the moon's distance from the earth—and truly, sixty times 4000, or 240,000 miles, is the distance of the moon from the earth, as proved by other more precise methods.

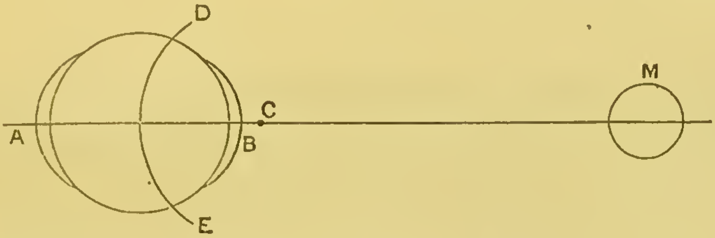
This experiment proves additionally the striking fact that in the six hours between the moon's being over a person's head and its setting, its distance from the person is increased by 4000 miles.

1307. The moon is, in comparison with other heavenly bodies, so near to this earth that with a good telescope the heights and depressions on its surface can be accurately measured, and correct maps of the surface have been made. Many of the irregularities referred to resemble so completely the mountains and craters of volcanic regions on this earth, that they are believed to be of volcanic origin.

1308. The fact which more than any other proves the kindred constitution of the moon and this earth is, that just as a mountain on earth attracts a plummet hanging near it, according to the law of mutual attraction or gravitation between them, so does the moon when appearing over any part of the ocean of this earth, lift or draw up towards her, as a flood-tide, several feet in depth of the ocean, and hold it there for hours, until her departure allows it again to subside.

Dr. Maskelyne, the astronomer royal in 1772, could estimate the mass of the mountain Skehalien, in Scotland, by its influence on a plummet hanging near it, so can we know the mass and weight of the moon by its influence on the tides of this earth. Into a tidal harbour like that of Liverpool the moon, in six hours, raises more water to a height of about twenty feet than all the pumping steam-engines in England could raise in the same time.

1309. In the phenomenon of the tides there is this paradoxical fact, that while on the side of the earth where the moon is seen, the water rises towards her, making there a flood-tide of many feet in depth, on the opposite or distant side of the earth away from the moon, the water similarly rises to an equal height. The fact is pictured in the adjoining diagram. M is the moon, B A the earth, and the protuberances of the water at A and B are the flood-tides in both situations at the same time. Thus, although the moon appears over any part of the earth only once in twenty-four hours, the flood-tide occurs there twice. The explanation of the tide at B on the side of the earth towards the moon offers no difficulty, and the tide at A on the distant side of the earth is the effect of the centrifugal force of the water at A not fully balanced by the attraction of the moon, which is nearly 4000 miles more distant from A than from B. The tide on the near side, therefore, may be called the *centripetal* tide and the other the *centrifugal.* It may be here recalled that when there is accumulation of water or flood-tide on two opposite sides of the earth, there must be deficiency of water, or ebb-tide, on the intermediate parts. It was explained in a former page (99) that when two mutually-attracting, or cohering bodies are revolving round each other they both really are revolving round the common centre of gravity of the two, here marked C.



It is to be observed here that the sun also produces tidal disturbance in the waters of this globe, but not nearly so great as that made by the moon, because of the vastly greater distance of the sun. When, however, the two influences either join or are in direct opposition, the stronger effects are produced called the spring-tides and the neap-tides.

1310. If this earth were all covered with ocean the two tidal waves would rise and subside uniformly all round it, but owing to the irregular forms of the land and of the sea-bottom, the simple progress is prevented. A striking phenomena connected with the tides is, that when the great tidal wave enters a broad inlet or bay which gradually contracts towards the inner end, as in the Bristol Channel, such wave becomes higher as it is compressed by the narrowing channel—in some places to the depth of nearly 100 feet, as in the bay of Fundy, in North America. Into the mouths of the Ganges, below Calcutta, the tidal wave often enters with steep front and great violence, forming what is called the *bore,* and causing great commotion among the boats and shipping in the river. In the silence of the night sometimes a person may hear the distant sound of the incoming flood, and may feel surprised to reflect that the apparently small moon, looking down from a calm sky, is really the cause of the uproar in the gulfs and rivers.

> "*This Earth is the third from the sun, in order of distance and length of year, of a series of such Globes, called Planets, revolving round the Sun, some of them being smaller than the Earth and having no moon, some being larger and having several moons.*" (Read the Outline, page 647.)

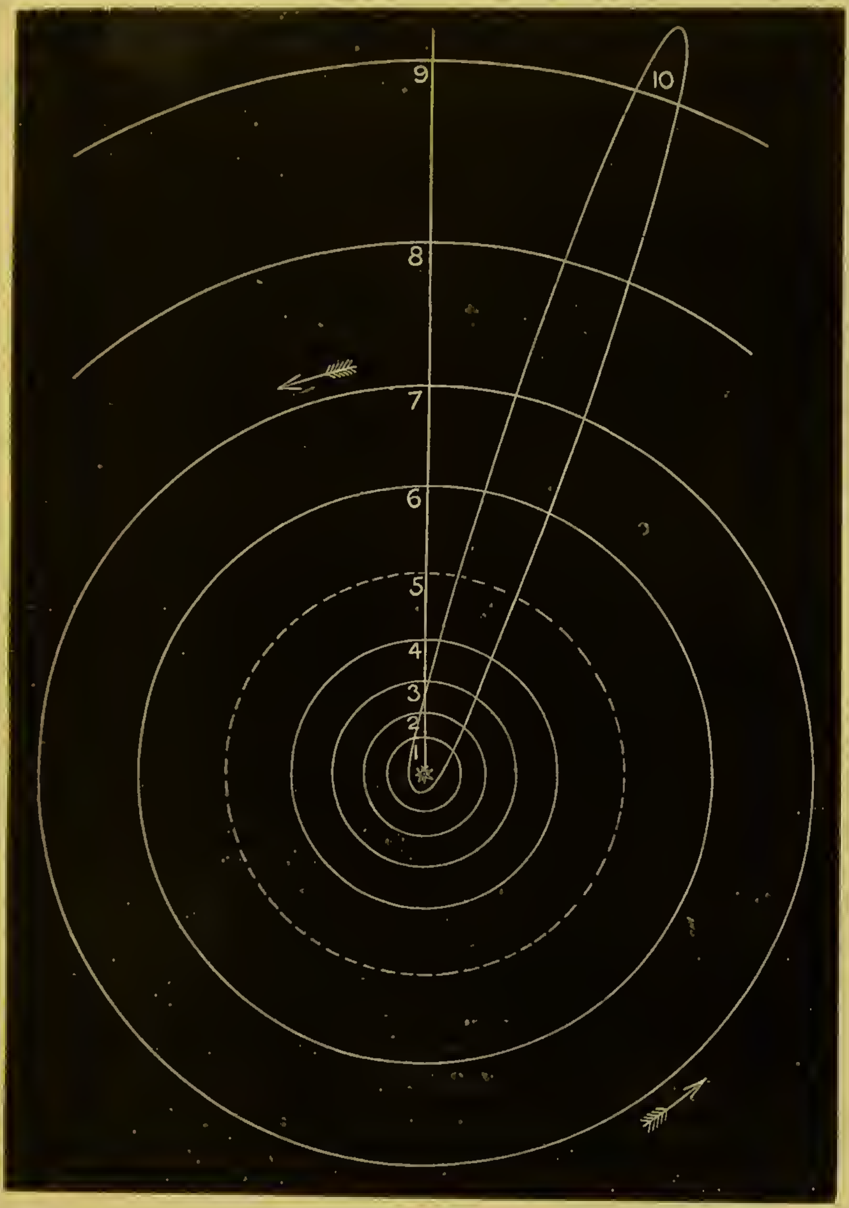
1311. The adjoining diagram will give to the student at once a general notion of the arrangement of sun and planets, which constitute what is called the solar system. It represents what an eye would see if looking down on the system from a great elevation on its north side. The central figure marks the place of the sun, and the numbered circles around that indicate the paths or orbits of the different planets moving in the direction shown by the arrows, as they would appear if every planet left a line of light where it passed along. The nine chief planets have their orbits here numbered. The following fanciful names were early given to them from the heathen mythology, and although without distinct meaning, are still retained:—1, Mercury; 2, Venus; 3, the Earth; 4, Mars; 5, a crowd of smaller bodies called planetoids, like parts of a large planet not yet cohering; 6, Jupiter; 7, Saturn; 8, Uranus; 9, Neptune.

All these bodies have globular form, proving that the law of gravitation, which accounts for the form of the earth, as explained in a former section, is active throughout universal nature. And they are all restrained in their orbits by the same balance of centripetal and centrifugal forces which rules elsewhere.

The sun, as already stated, is the only self-luminous body in the system, and, therefore, the most important in it. The sun's presence makes day, its absence night; its more direct beams make summer, its less direct make winter; and on its numerous influences depend the life and well-being of the animal and vegetable creation.

1312. Thinkers have speculated on the probable mode of origin of this glorious system, inquiring whether it may have come into existence at once, nearly as we now see it, by the will of its Divine Author, or whether, like all the subordinate objects, of which men may witness the beginning, it was built up gradually by successive additions of minute particles, in obedience to laws which Divine wisdom had ordained.

The most majestic oak now standing in any forest was once only a small acorn or seed; the whale, the elephant, the lion, and even every human being now existing in the world, commenced visible existence as a minute ovum or embryon, which has been gradually built up to the dimensions of maturity by atom joined to atom.



1313. It is known that all the elementary substances of which larger masses in the world are formed, namely, the metals, carbon, sulphur, and about sixty others, are resolvable by strong heat into a gaseous or aëriform condition, invisible to human sight; so that this solid globe, and all within and upon it, might, by heat, be changed into a vast transparent mass. We may adduce as illustration of this truth the phenomena now to be described.

1314. A person looking up into a perfectly transparent sky may see there nought but bluish space or extension, although aware that the space is occupied by a material atmosphere. A change then occurring in the temperature, or electrical state of that atmosphere, may suddenly cause a haze to appear. The moist particles of the haze may then multiply and become a dense cloud, and that moisture may soon condense, or coalesce, into drops of rain; these, with increase of cold, may be frozen into solid snow-flakes or hail-stones, which mutually cohering into larger masses, and descending with violence to the ground, can demolish any fragile objects, and may even kill animals of considerable size. If the atmosphere during such changes have vorticose motion of whirlwind or cyclone, the solid masses must share such motion.

1315. If something like this solidification of gaseous invisible matter had occurred long ago on a prodigiously larger scale, planets instead of hail-stones might have resulted, and the present solar system might have come to occupy the space previously held by the transparent cloud. Such supposition would seem to explain why all the planets, and all the satellites about the planets, revolve in the same direction, and why the individual planets, and even the sun himself, rotate about their own centres in that direction, and further, it accounts for the very remarkable fact that in the wide space between the two planets Mars and Jupiter, where, to maintain uniformity of condensation throughout the space, a large planet should have appeared, but did not, the improved telescopes of modern times discover a great number of smaller masses revolving, which, if united, would form such a planet as seemed due to the situation.

1316. This sketch is presented, not as the history of the origin of the solar system, but, by analogy, as a familiar type, to facilitate the conception of the great facts really existing.

The invention of the telescope and other valuable means of observing facts, and the improved modes of computation devised in recent times, do not assert the impossibility of some such origin of the solar system as above sketched.

The table which here follows of the globes of our solar system, with their exactly ascertained distances from one another, their comparative bulks, their times of rotation, or length of days, and times of revolution, or length of years, and the number of their moons, is in complete harmony with the ascertained laws of inertia and gravitation, as explained by Sir Isaac Newton.

1317. *Table of the great bodies of the Solar system, with their sizes, distances, and other particulars.*

PLANETS.	Mean *distances* from the SUN in Millions of miles.	*Bulk* as compared with this Earth.	Time of *Rotation* or length of DAY.		Time of Revolution or length of YEAR.		Number of Moons.
			HRS.	MIN.	YRS.	DAYS.	
Mercury .	36	$\frac{1}{17}$th	23	50	0	87	None.
Venus . .	68	$\frac{19}{20}$ths	23	21	0	224	None.
Earth . .	93	1	24	0	0	365$\frac{1}{4}$	1
Mars . . .	142	$\frac{1}{7}$th	24	40	0	686	None.
Planetoids .	between 200 and 300	..	..	..	..	..	..
Jupiter . .	485	1,414	9	55	4	332	4
Saturn . . .	890	735	10	16	10	760	7
Uranus . .	1,800	82	7	5	79	205	6
Neptune .	3,447	..	..	..	..	..	3 already discovered
Moon . .	from Earth 24,000 miles.	$\frac{1}{50}$th.	27$\frac{1}{3}$ days.		..	..	..
SUN . . .	93 millions	1$\frac{1}{3}$ millions of times larger.	25$\frac{1}{4}$ days.		..		..

1318. In thinking of the stupendous magnitudes and relative distances of the bodies which constitute our solar system, it facilitates the conception to figure before the mind an arrangement exhibiting nearly the like proportions on a vastly smaller scale, among known things. Thus, if a Londoner imagines a globe, of about eighty feet in diameter, placed on the summit of

St. Paul's Cathedral, to represent the sun, the comparative distances and magnitudes of the planets would be roughly as follows:—

Mercury, a	globe of 5 inches diameter at	Putney.
Venus	11 inches	Richmond.
The Earth	12 inches	Windsor.
Mars	9 inches	Oxford.
Jupiter	10 feet	Liverpool.
Saturn	7 feet	Durham.
Uranus	6 feet	Edinburgh.
Neptune	5 feet	Orkneys.
Our Moon	3 inches	30 feet from the Earth.

It is a matter of pure arithmetical computation that a railway train at a uniform speed of forty miles an hour would need nine months to reach the moon, 302 years to reach the sun, and a thousand times as much to reach the nearest fixed star.

One is surprised to think how small a portion of the space of the universe is occupied by the substance of the sun and the worlds around him.

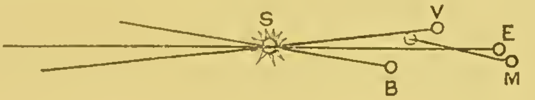
1319. As when looking edgeways at a wheel or circle, the eye sees only a straight line, and if the wheel be rotating, and carries some object on its side near the outer edge, that object does not appear to move in a circle, but to sweep across the centre of the wheel, from side to side, almost in a straight line; so to an observer on earth, looking at another planet revolving in an orbit nearer the sun, the planet appears to sweep in a nearly straight line alternately to the east and to the west of the sun. The planets Venus and Mercury thus being nearer to the sun than the earth is, appear to an observer on earth, during one half of their revolution, as evening stars east of the sun, and during the other half as morning stars west of the sun. The apparent confusion of the planetary motions observed from the earth is much increased by the fact that the earth itself is constantly changing its place.—Had men not become able constantly to measure the changing distances of the other planets from the earth, the course of their motions could not have been accurately ascertained.

1320. If the orbits of the planets had been all *exactly* in the same plane like that of boats sailing round a ship at anchor, the boats being at different distances and having different speeds, whenever two planets happened to be in the same line from the sun, the nearer one would have been seen from the more distant, crossing the face of the sun, and exhibiting what is called a transit, as when the planet Venus so crosses it. But the planes of the orbits do not so perfectly coincide, and hence the rarity of the observed transits. The two last transits of Venus took place in the years 1761 and 1769, and the next will be in December, 1874. The exact observation of these transits aids much in determining the distance of the sun from the earth, and hence they are watched with much interest.

1321. The transit across the face of the sun of a comparatively small and distant body like Mercury or Venus, when seen from the earth, does not attract popular notice; but when the intercepting body is near the spectator, as when our moon is passing between the earth and the sun, it may hide from the spectators here, for a time, the whole face of the sun, as a hand held up before the eyes can do, and then occurs the phenomenon deemed the most awful in nature while not understood—the total eclipse of the sun. When, on the other hand, the earth happens to be the body intercepting the sun's light, radiating towards the moon beyond it, the occurrence of opposite nature takes place, of the eclipse of the moon.

1322. These eclipses may be total, or partial in any degree, according as the position of the intercepting body is central to the other or not. A phenomenon illustrating this subject strikingly is that called the *annular* or ring-eclipse of the sun. At the ordinary distances of the sun and moon from the earth, they occupy nearly an equal breadth of the sky, so that the moon intervening can hide the whole face of the sun, but when in particular parts of the orbits, the sun is nearer and the moon is more distant than usual, and then the intervening moon does not quite cover the sun, but leaves a ring of his body visible around its own circumference.

The adjoining figure exhibits to the eye the relative positions of planetary orbits, of which the planes do not coincide. S marks



the place of the sun, E represents the end of the line or plane of the earth's orbit, V that of another planet, B that of a third, and M that of the moon. It is evident that there can be no eclipse of either kind, or transit, but when the sun and the two other bodies are all in the same straight line where two planes cut or cross each other.

1323. To think, as our remote forefathers did, that the wondrous array of the many planets visible from this earth serve no purpose but to adorn its nocturnal sky, would now appear absurd indeed; but whether they are inhabited by beings at all resembling the men of this earth we have not the means of knowing. All the analogies favour the opinion that they are the abodes of life and its satisfactions. On this earth there is no place so hot or so cold, so illumined or so dark, so dry or so wet, but that it has creatures constituted to enjoy life there.

1324. The sun, as has been already said, is the only body in the system which is self-luminous. How its intense temperature and brilliancy are maintained is not yet well known; but experiments made in late times upon the sun's light, refracted and decomposed by passing through transparent prisms, give assurance that the same material elements which meet in the composition of the bodies on earth exist also at intensely high temperature in the luminous atmosphere of the sun.

1325. There are reasons for thinking that many of the same chemical elements exist also in the different planets, although the density of the planetary masses is found to be very different. If the planets are homes of happiness to intelligent beings, the constitutions of these beings must differ much from that of the inhabitants of this earth. Could a traveller from hence visit the other planets he would find, among other particulars, as follows:—

A. *Mercury.*—The general temperature greater than that of the warmest day in the warmest part of this earth,—the sun appearing of three times the diameter, and, therefore, with nine times as much surface as when viewed from the earth; the year lasting only eighty-seven days; the day being of nearly twenty-four hours.

B. *Venus.*—Also very hot, but animals of this earth might bear the climate towards the poles. This earth, from Venus, would appear as large as Venus does from the earth—accompanied always by its moon, revolving a short distance from it; the day lasting nearly twenty-four hours, as it does on this earth and on Mercury.

C. *The Moon.*—The day just half as long as the month of this earth, and the night in the same proportion. As the moon, while revolving round the earth, has always the same face or side towards the earth, if there were inhabitants on the distant side of the moon, they could never see the earth but by travelling round their globe towards it, and the inhabitants on the near side would have the earth always in view and in the same part of their sky, spinning round once in every twenty-four hours, and exhibiting to them in succession all its continents and seas. A man weighing 150 pounds on this earth would weigh only about a fifth part as much on the moon. There is not clear evidence of there being water or air in the moon.

D. *Mars.*—Colder much than this earth. The regions about the poles in its winter season become white, as if covered with snow, which disappears again when summer returns. Owing to its great distance, the sun appears at it but half as broad as when seen from this earth. The body of the planet is of reddish hue, like the red sandstone rocks of the earth.

E. *Planetoids.*—Nearly a hundred are already known, all discovered within the present century; some of them are not 200 miles in diameter.

F. *Jupiter.*—The largest of the planets. A man there would weigh nearly three times as heavily as on this earth. The length of day, or rotation on the axis, is of only ten hours and forty minutes. The consequent great centrifugal force at the equator causes the bulging there to be so great as to be evident to simple inspection. There are four beautiful moons constantly revolving round the planet, which, to the astronomers on this earth, are like the hands of a vast unerring time-piece. Owing to the great distance, the sun appears at Jupiter to be twelve times smaller than as viewed from the earth. Dark bands are seen on the surface of the planet parallel to the equator, caused, it is judged, by clouds carried along on winds there, corresponding to the trade-winds on this earth.

G. *Saturn.*—Still colder than Jupiter. It has seven moons wheeling round it, and, additionally, has a broad, double, or more complex flat ring revolving between the moons and the body of the planet.

H. *Uranus.*—Although about eighty times larger than this earth, it is so distant and apparently small that it was not discovered until 1781, when Sir W. Herschel's eye and telescope fell upon it.

I. *Neptune.*—Discovered only ten years ago. Its existence had been suspected for some time, as causing, by its attraction, an observed disturbance in the motion of the planet Uranus, which in the series of planets, is the next to it. Two moons of Neptune have been discovered, and perhaps there are more.

The two last-named planets are so remote that the sun can appear to them little more than a very bright star.

"*Around the sun there revolve also, in very elongated elliptic orbits, many bulky transparent masses, as of gaseous matter, called Comets.*" (Read the Outline, page 647.)

1326. Until it was ascertained that the comets revolve in orbits as perfectly in accordance with the laws of inertia and gravitation as the planets themselves, their occasional appearance in the sky excited in the public mind extreme awe and terror. They were deemed instances of direct interference of Divine power with the usual course of nature, intended to serve some purpose of warning to men, of Divine displeasure and of coming disaster. Such feelings have only gradually passed away, although the periodical return of many of the comets is now foretold nearly as of the planets. Comets have little weight or momentum, and one, in the year 1830, passed among or near the moons of Jupiter without at all disturbing their motions. The comet distinguished as Halley's has a period of nearly seventy-five years.

1327. It completes our sketch of the bodies existing within the bounds of our solar system to say that there are masses innumerable, invisible from their smallness to human sight, until they come within the limits of our earth's atmosphere, which, owing to the great condensation of the air and the friction produced by their rapid motion through the atmosphere, become heated to redness, and, being obstructed, fall to the earth as aerolites or meteoric stones. They consist of chemical elements, all known on earth, and chiefly of iron. There are strong reasons for believing that there are vast bands of such minute masses revolving round our sun as the planets do, or as the rings of Saturn revolve round it, which the earth at times encounters in its orbital progress. Their appearance has occurred frequently in the months of November and August. Sometimes they have seemed to fill the sky almost as thickly as flakes of falling snow. These bodies have been called shooting or falling stars, aërolites, &c.

Section 6.—"*The sun himself is but the nearest to this earth of unnumbered similar bodies far apart in boundless space, of which the others, because of their vast distance, appear to human sight very small, and are called stars.*" (Read the Outline, page 647.)

1328. Such is the dazzling splendour of the sun at noon, seeming to fill all space with his light and other influence, that our forefathers, with their short experience, might well suppose one sun to be sufficient for a universe. Thousands of years passed before men got views wider and more true.

1329. All persons are aware that to the human eye objects appear smaller and less distinct the farther they are removed from the observer; but only those who have looked more carefully into the subject know how strictly true this is to any extent.

A great ship, with all sail ready set, leaving a harbour, may conceal or cover half the sky from a spectator near. As it increases its distance, it covers less and less of the sky, and when ten miles away, it is seen only as a dark spot on the horizon, which a finger-nail held up can completely hide.

A small coin held before the eye covers or hides one of double diameter at double distance, and hides objects of always greater diameter as the distance increases, such as a balloon, the moon, the sun.

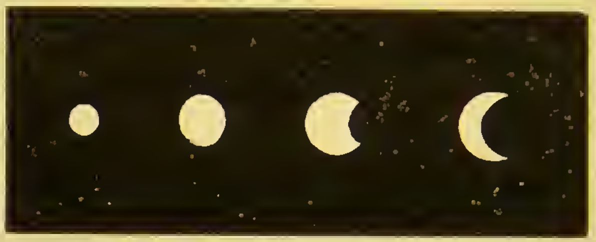
In the diagram at page 553, which shows a row of similar stone blocks as they appear at increasing distances, those farther off become smaller and smaller in succession, and at S, called by painters the vanishing point, they appear so small that they cannot be separately distinguished.

It is an interesting spectacle to see a balloon crossing the face of a full moon. The balloon appears a small, scarcely visible spot, because, it may be, a thousand times farther off than when seen before rising; but the moon appears of her ordinary breadth, because, not by a thousandth part, nearer or farther off than usual.

From such facts and reasonings, we know that at the planet Mercury the sun appears three times as broad as from this earth; from the planet Mars it appears only one-third part as broad as from the earth; and from the planet Neptune it can appear only as a very bright star. From any one of the fixed stars, or from a planet near that, it would be truly a star.

An approaching comet when first seen appears so minute as to be visible only through telescopes; as it comes nearer, it seems larger, and its luminous tail may stretch across half the heavens. Some inquirers have conjectured that the change in the apparent size of a comet as it approaches the sun, is due to expansion from heat, and not because the distance from the observer is lessened.

The orbit of Venus is nearer to the sun than the orbit of the earth; and as these two planets revolve with different speed, they are at one time much nearer to each other than at another. Photographic portraits of Venus, made at the different distances, differ in size, as here represented, the smaller figures recording the appearance at a distance, the larger, that when nearer.



It is to be remarked of Venus and Mercury that, being nearer to the sun than the earth, they show to spectators on earth the same phases as the moon; so that Venus viewed through a telescope which magnifies, appears to be the moon in her quarters.

1330. The parallax of our sun is only eight seconds and a half ($8\frac{1}{2}''$) of the sky or field of view, which declares a distance of nearly ninety-three millions of miles. The nearest stars have parallax of only about one second, which declares a distance of one thousand times greater than that of the sun; and as only a few stars have even so much as that, all the others must be at still greater distance. Having no means of knowing how much, we may conjecture it to be in proportion to the brightness. There is reason to think that our sun is not the largest body of his kind.

1331. The mind finds it so difficult to conceive clearly these magnitudes and distances, that some inquirers have been disposed to deem the whole matter a delusion; but irresistible facts of recent discovery have settled the question. Sir William Herschel having descried through his telescope two stars, appearing nearly in the same line from the eye, like two distant trees in a forest, he hoped that the lateral movement of the earth in its orbit would either open out or close the space between the stars, and so give a parallax, which would help to declare their distance from each other and from this earth.

1332. The result of the experiment was not, however, what he expected and desired. But, strange to say, it furnished proof that one of the self-luminous sun-like bodies was revolving round the other, or rather that the two were revolving round their common centre of gravity, as planet and satellite do. This observation led to the discovery by him, and soon after by astronomers generally, of many such unions, and not only unions of two, but of three or four such stars. It was seen, too, that they all obeyed the same laws of inertia and gravity, which regulate the motions in our own solar system. The periods of revolution in a considerable number of these unions have been found to be shorter than a hundred years, in others far to exceed that.

1333. It is known that two bright lamps, near to each other, if viewed from a great distance, appear to the naked eye as one, although a telescope immediately shows them apart. So it is with the double stars. Of Castor and Pollux, the former is a double star, of which the two members appear of different colours. More than a thousand double or multiple stars are now noted in our star maps. No reason is assigned why these multiple suns should not have each its planets around it.

1334. It is further to be stated here that some of the stars have periodical alternations of brightness and dimness, proving rotation about an axis like that of our sun, or the existence of intervening opaque bodies revolving about them. Some have had times of exceedingly increased brightness, making them surpass for a while any other star in the sky. Of these some have since totally disappeared, while others have reappeared after long intervals.

1335. Besides the stars, near enough to our system to be easily counted separately by the naked eye, there are innumerable others only brought into view by telescopes, as in the so-called Milky Way, stretching all across the sky. There are also in the sky many luminous patches called nebulæ, or starry cloudlets, sending us only diffused light, but which to powerful telescopes become crowds of separate stars. Our own sun seems to be one in such a mass. The forms of many of these assemblages of stars seem to indicate that great movements are going on among them of which we do not yet understand the nature, There is scarcely a doubt that our sun and his planets have a motion towards the constellation Hercules.

MEASURE OF TIME.

Section 7. "*The motions or changes among the heavenly bodies are found to be so regular that astronomers now foretell, in almanacs published years before the events, the exact times of coming eclipses, occultations, transits, and other phenomena.*" (Read the Outline, page 647.)

1336. The current of time, to use the common phrase, is known and measured by men in the observed progress of motions going on among the objects around them.

1337. To measure any given thing or magnitude is to choose as a unit of comparison a certain amount of the kind of thing to be measured, and then to find how many times or parts of a time such unit is contained in the new quantity to be measured. For example, in regard to *length*, having chosen the human foot as a standard unit, always and everywhere present and ready for use, men can say how many feet long, or high, or broad, or deep any other object is. This proceeding is so obvious, and, therefore, so natural, that it has been adopted in all ages and countries.

1338. In regard to *time*, there are certain portions or units naturally distinct, which have been everywhere used as standards of comparison. The most obvious of all is that called a day, or a day and night, which passes between the rising of the sun on one morning and his rising on the next. Man's life may be said to begin afresh every morning when the sun's light rouses him from a state of comparative unconsciousness to some form of activity through the day.—A second larger measure of time, comprising many days, is that which begins with every new moon, and ends when the next new moon appears. It is named from the moon, a month.—And there is a third still larger natural portion, which extends from the season of warmth, called summer, through other seasons of lower temperature, until a succeeding summer arrives. This is called a year. It was judged at first to consist of about 360 days.

If these three standard units of time stood in such precise fixed relations to one another as the inch, foot, and yard do in regard to length, any one of them might be used as a common standard, because of any given amount of one, an exact equivalent can, by simple computation, be named of any other; but this is not the case. The lengths of days and nights are different in different seasons of the year and in different latitudes; the month is not measured exactly, or without a fraction, by a certain number of days and nights, nor is the year measured more exactly by a certain number of equal months. In consequence of this, much confusion and uncertainty have reigned in the comparison of times and the dates of certain events.

1339. Some strictly uniform or invariable motion in nature had, therefore, to be sought, with which all others might be compared.

The only unchanging motion and portion of time yet known to man, is that of one complete rotation of the earth on its axis —that is to say, the time from the instant when a known star is seen to flit or make its transit across the central line of a telescope firmly connected with the ground, to the instant of the reappearance of the star there on the following night. And artificial timekeepers, or chronometers, have now been constructed which divide that interval, called the sidereal day, into any desired number of perfectly equal parts. It has been found convenient to divide the whole period of a day and night into twenty-four parts, called hours, the hour into sixty minutes, and the minute into sixty seconds. Clocks can now be made so perfect, as scarcely to err by a beat of the pendulum in a whole year.

1340. Had the apparent motion of the sun coincided exactly with that of the stars or general firmament, the sun, by the appearance and disappearance of which the general business of society must be regulated, would have been at once regarded as the perfect index of passing time; but the motions do not coincide, for the sun appears, in the course of the year, to travel among the stars once round the whole firmament. That appearance is produced, as already explained, by the real motion of the earth in its annual motion round the sun.

The apparent and real motions of the sun and earth, however, are in strict accordance with the laws of inertia and gravitation expounded by Newton; but, as explained in Art. 1299, the orbits of the earth and other planets are not perfect circles, and the forms of rotating masses, like the planets, because of the greater centrifugal force acting near their equators, are not perfect spheres; and the consequences are, slight perturbations or deviations from absolute uniformity in their motions. These, however, like other oscillating changes, compensate one another during complete circuits, and do not vitiate the computation of average mean times. The sun, or sun-dial, in marking time, is as much as sixteen minutes behind the sidereal clock or mean time in the month of February, and is as much before it in the month of November, as shown in the table of what is called the *equation of time.* The relation of solar and sidereal time being now perfectly understood, and sidereal clocks being placed in Observatories, the advantages of both systems are obtained.

1341. The Egyptians seem to have been the first to note with tolerable exactness the number of days in the year. They observed the length of shadow produced by a perpendicular stile or pole on a level floor, and in summer, when the heat-giving sun seemed at noon to come the nearest to the zenith, or summit of the sky, and consequently made the shortest shadow, they deemed that day the middle of the summer and counted the days until that happened again. For a considerable time it was held that the number of days in the year was 365; but in this there was an error of nearly six hours, for after a time it was found that the day of shortest shadow came later, than if the year were of only 365 days, by one day for every four years. The year was then held to be of 365 days and a quarter, or 365 days and six hours.

1342. Julius Cæsar, having had the aid of an Egyptian astronomer, commanded that the year in the Roman Empire should be held to be of 365 days, with the insertion of an additional day in every fourth year, now called leap year. It was afterwards ascertained, when astronomical instruments were further improved, that there still remained a fraction in error of about twelve minutes, which, having accumulated up to the year 1582 of the present era, amounted to eleven days; Pope Gregory XIII. ordered this to be rectified by the addition of eleven days, and a simple management of the leap year to prevent error for the future. This was called time according to the new or Gregorian style, differing now from that of the old or Julian style, still used in a few countries, by twelve days. According to the rule as modified in 1582, there cannot arise an error of one day in 5000 years. Laplace, by comparison of present and ancient records, declared that the length of the sidereal day has not varied the hundredth part of a second for the last 2000 years.

Geology.

Section 8. "*There are clear evidences all over this earth that, during past ages, slow but great changes have been going on in the distribution of land and water on its surface, the kinds of animals and vegetables spread over it, and other particulars.*" (Read the Outline, page 647.)

1343. Living beings can exist and thrive on this earth only where they find a sufficiency for them of four great necessaries of life—namely, *food* or aliment, *pure air*, *warmth*, and *shelter* against the weather and enemies. The inferior animals depend on what of necessaries any locality spontaneously produces, their number being limited accordingly; and even human beings in the condition called *savage*, which means men without knowledge of the general laws of nature, and of the arts founded on them, and gradually growing up in civilized communities,—are nearly in the same low state. This has lately been seen in Australia, in Tierra del Fuego, near Cape Horn, and elsewhere. But men, under favourable circumstances, by the exercise of their high endowment of reason, can compel the earth in almost any region to produce the four necessaries in vastly greater abundance than where no art is used. Thus the human population of a civilized country, instead of appearing as a few wandering savages spread over a wide extent, gradually multiply until great cities arise in the midst of well-cultivated land. The land furnishes not only the essentials of food and clothing, but the means of innumerable conveniences and gratifications, of which rude men have no idea.

The arts of agriculture and of rearing tame animals to furnish sustenance and clothing, constituting for a long time, in addition to the arts of defence against enemies, the most important parts of the business of civilization, were consequently held in high honour.

1344. At certain stages in the progress of civilization men would discover, at first by accident, here and there, under the surface of the earth, substances like the metals, and stones which, in various ways, could aid the husbandmen and others in their labours. With implements formed of metal, for cutting and breaking, most other substances can be shaped to answer useful purposes. For instance, by the plough so made, the ground can be caused to produce many times more corn or other kinds of food than would grow upon it in a state of nature; and with mallets and chisels, dwellings for the people and other structures could be formed of stone, incomparably more durable than the earth or lumps of clay hardened in the sun, which had been previously employed.

Now the knowledge of where best to find the various precious things, hidden beneath the surface of the ground, for the innumerable uses to which they are now applied is called GEOLOGICAL knowledge (from GE, *the earth,* and LOGOS, a discourse.)

1345. In the subterranean search for what might be useful, men after a time found that the different substances constituting the crust of the earth to a considerable depth, were not lying in absolute confusion or without order, but in beds or strata, more or less distinct from one another. The study of such order singularly aided the business of subsequent search. Geological maps of mineral arrangements have now been rendered gradually more and more complete, and save, to miners and others, much of the labour and expense of chance-searching.

1346. During the subterranean labours referred to, men gradually found what they had little expected, namely, distinct evidence of constant changes going on upon the earth, effecting momentous results. As travellers in modern times, by breaking into the tombs and buried cities of Egypt, Asia, and Italy, read the history of mankind and human arts as they existed thousands of years ago, so do men now, by penetrating much deeper, read the history of events far more remote,—they find the remains of races of animals and vegetables which have now been long extinct, and proofs that many species of those presently existing had not yet appeared.

1347. They have found at last that the contrast, often in common speech assumed to exist, between the transient and perishable nature of human works, like the pyramids and palaces of ancient Egypt and Asia, and what they called the everlasting rocks, mountains, and continents of nature, was a fallacy originating in the shortness of human life and narrowness of experience; the truth being that there is a close analogy instead of a contrast. Thus they have discovered that it is the course of nature for every visible thing upon or about the surface of this earth to be constantly changing, according to laws which Supreme Wisdom has ordained. The greater part of the vegetable covering of the earth decays, and is renewed, every few years. Even the most gigantic forest-trees, after flourishing for centuries, decay and die; and then by the chemical action of the oxygen of the atmosphere, with rains and winds, heat and cold, they are gradually resolved into their chemical elements, which soon are diffused in the atmosphere to become the substance of succeeding trees. So the whole of the animal creation is being similarly changed and renewed at short intervals; and even of men themselves, only a few live to the age of a century. This is too short a time for them individually to note the prodigious changes going on in the form and condition of the dry land all over the globe. In respect to the land, the same chemical and mechanical action of the atmosphere,—its rains, winds, heat, and cold,—are wearing down the hardest rocks to minute particles of sand and mud, which the carrying power of running water in rivers then conveys to the ocean and there deposits. Such deposit gradually, under the enormous pressure of deep water and its own increase, hardens into rock, and is afterwards, chiefly by the force of subterranean fire, upheaved above the sea level to become the land of a new state of the world. This land again, after a time, is worn down by the never-ceasing agencies above mentioned, to become new sea bottom, and possibly again, new land and mountains.

1348. The fragmentary wearing down everywhere of the land thus carried to the sea by the rivers is, although little noticed by ordinary observers, of enormous amount. By taking from the centre of a great river, like the Ganges or Mississippi, a gallon of water, allowing the mud or sandy particles to subside, and then weighing the deposit, and afterwards, by measuring the depth and width of the channel, and the speed of the current, it is possible to tell nearly the amount of solid matter which is being constantly poured into the ocean beyond the mouth of the river; and what is true of any particular river is true of all the streams of the world. It is thus ascertained that the Ganges every year brings down and deposits on the bottom of the Bay of Bengal more solid matter than, if spread over the surface of England, would be a layer exceeding an inch in thickness. Such transported matter forms, when deposited, what are called the deltas or level lands, seen to be increasing wherever a stream empties itself into a sea or a lake. Much of the flat land in Lower Bengal has been thus formed by the Ganges. Nearly 500 miles of the southern portion of the United States of America has thus been formed by the Mississippi. In the course of most great rivers there are extensive flat breadths of land, which are ascertained to have been formerly lakes, gradually filled up by the deposit of sand and mud brought by the river from higher levels. The courses of the Rhine and the Mississippi show many such levels.

1349. The sand and mud produced by the wearing down of land, as above described, is not carried to the ocean floors unattended, but takes with it whatever else falls into the streams, and can be floated along in them. Thus, the carcases or partial remains of animals and of vegetable growths are carried along and are soon buried, to be so far preserved in the marine deposit. Such skeletons, single bones, teeth, &c., are what tell the tale of earlier forms of life on the planet, and show that a gradual change and succession of species has been going on. The mammoth Megatherion, Ichthyosaurus, and numberless other creatures which abounded formerly, but exist now no more, are of the kinds referred to.

1350. The sea bottom receives not only what is brought down by river currents, but also a vast amount of like material produced by the ever-rolling and breaking of the waves on the sea shores all over the earth. On the east coast of England, for instance, it is ascertained that in many parts more than a yard of cliff or solid shore is worn away every year by the waves, to be spread by the tides upon the sea bottom.

1351. It is to be remembered also that the ocean has its living inhabitants even more abundantly than the dry land, the shells and hard parts of which, after the creatures are dead, are more enduring than the bones of land animals. These shells and remains in many places have accumulated to a thickness of thousands of feet. The coral rocks, which form many islands in the Pacific Ocean, are all the former dwellings and coverings of marine creatures secreted from their bodies and built up by them. The chalk hills and cliffs of England and the west of Europe, are almost entirely the coverings of other minute marine creatures.

1352. The upheaving of the matters of these river and tidal deposits into land is a less regular process than that of the depositing. It occurs often during earthquakes and other volcanic action. In the year 1835, during the activity of volcanoes in the Andes, within a short time about 300 miles of the western coast of South America, with the chain of the Andes as part of the upheaved mass, was lifted several feet higher above the sea level, rendering to that extent more shallow all the bays and harbours, and in some places uncovering great extents of rocky bottom, the shell-fish adhering to which, during their putrefaction, produced sickness among the inhabitants along the coast. In many places on the sea-shores there is evidence of frequent repetitions of such partial upheavals of the land. The Alps in Europe, the Andes in America, and the Himalayas in Asia, exhibit beds of enormous thickness of the shells of marine creatures, deposited of old on sea bottoms, and now become the substance of mountains, thousands of feet above the sea level. In the British Isles, with the exception of the crystalline mountains of gneiss, granite, &c., on the west coasts, the land exhibits the structure of old marine deposit.

1353. Where the subterranean heat to which deposits brought from worn-down land have been subjected has been very great, the masses have been more or less melted (as a mixture of sand and soda is by strong heat melted to form glass), and so converted into the crystalline rocks, as granite, &c. Where the heat has been less strong, the deposited material has become only mechanical aggregates, cohering by the effects of the enormous pressure long continued of superincumbent masses to which they have been subjected. Beds of vegetable matter, when so heated and again cooled, may become what is called stone coal or anthracite; if less, or not at all heated, they form the common bituminous coal, from which trees can be detached, exhibiting completely the forms they had when growing on the surface.

1354. It is evident from what has been said here, that the details of geology can be studied only by persons versed in chemistry and biology, or the natural history of animals and vegetables. I have to leave such details, therefore, to be studied in the published systems of chemistry and geology, such as the admirable "Principles of Geology" of Sir Charles Lyell, the appearance of whose book about thirty years ago formed an epoch in the science of geology, as the discoveries and writings of the illustrious Herschels, father and son, have done in astronomy.

Some facts described or referred to in this section may at first excite in the minds of students wonder and awe; but continued reflection shows clearly that all is the work of Infinite

Power directed by boundless wisdom and benevolence. Passing on from first impressions, persons rejoice to find themselves part of the glorious creation contemplated. The notion which had arisen in a few minds unfavourably trained, that such a universe could spring from blind chance, yields at once to the fuller study. An esteemed popular author has said, "An undevout astronomer is mad." And yet astronomy is only one part of the mass of creation, a part extending widely, but perhaps less readily comprehended by minds of ordinary attainments than narrower portions, such as the structure and powers of the eye, and many other bright revelations of the divine attributes. Our honoured Shakespere, who has given delight to all his readers by clothing in simple but clear expressions many of the noblest thoughts and feelings of our nature, has said what the enlightened mind everywhere echoes, "there are sermons in stones, and good in everything."

APPENDIX.

ON THE ART OF MEASURING.

OUTLINE.

> " *To measure anything is to choose some convenient amount of the thing to be measured as a standard of comparison, and then to find, and to say, how many times, or parts of a time, that amount is contained in the quantity about which there is question. Thus, the human foot is such a standard of length, and the ten fingers serve as a standard of reference for numbers.*"

1355. A popular notion exists with respect to the *Science and Art of Measuring* (called *Mathematics*, including *Arithmetic* and *Geometry*), that ordinary minds have much difficulty to understand them. Four doggrel lines repeated among children at school, to account for their own tardy progress, is evidence of this.* The truth, however, is, that the difficulty has arisen more from faults in the modes of teaching than from the nature of the subject itself. These faults are now being gradually corrected or avoided.

It had been remarked that particular schools, during certain periods, were remarkable for training able mathematicians, while others as remarkably failed, the true explanation was, not, that more intelligent youths had been sent to the one school than to the other, but that the methods of instruction were different.

1356. In modern Europe, one of the unfavourable circumstances in regard to mathematical education has been, that the early books on the subject, which, owing to their merit, have come down to late times, were written in Greek or Latin, and when translated into modern tongues, were allowed to retain many of the Greek and Latin terms, instead of having these replaced by equivalent words of modern tongues. Children and others, therefore, have had to learn not only a new branch of science, but also a considerable amount of new languages not taught by a good method. The words of one's mother tongue give comparatively clear ideas of things, as recalling the individual's own experience, while strange words may produce indistinct and erroneous conceptions in the learner's mind and prove repulsive. The following example illustrates this:—

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* Multiplication is vexation,
Division is as bad,
The Rule of Three does puzzle me,
And Fractions drive me mad.

Old Terms little changed.	The Old Words.	Corresponding English Words.
Arithmetic.	Αριθμος, *Arithmos.*	Number.
Geometry.	Γεωμετρια, *Geometria.* Ge, earth. Metron, measure.	Ground measuring.
Sphere.	Σφαιρα, *Sphaira.*	Globe or ball.
Mathematics.	Μαθησις, *Mathesis.*	Learning.
Angle.	Angulus.	Corner, nook.
Triangle.	Tres.	Three corners.

Knowledge of modern English or French can help a student very little to understand and remember the meaning of such words as the following, which present themselves constantly in lessons of technical mathematics:—lemma, scholium, ratio, frustum, theorem, scalene, isosceles, absciss, homologous, &c.

1357. It is a striking fact that the general business of measuring and counting the things in the world around men, has always and everywhere been carried on by reference to standards of comparison, for size and number, taken from man's own body.

1358. It has been the practice to take as the readiest general unit of length, that of the human foot, and for some limited purposes also that of the hand, the span, the cubit or fore-arm, the step, the fathom. With a unit of any known length, and the power of numbering, any magnitude whatever, can be measured and clearly described in words. A man may be six feet tall, a horse fourteen hands high, a whale 100 feet long, a mountain, like Mont Blanc, 15,000 feet high. A length of a thousand steps is called a mile, from the Latin *mille*, a thousand. This earth is 8,000 miles in diameter; the distance between the earth and the sun is nearly ninety-three millions of miles. Then the dimension of length can measure readily any other dimension, as of superficial area or surface by the *foot-square;* of solid bulk by the *foot-cube;* and the weight of a certain bulk of water connects weight with bulk. As the length of the foot differs a little in different persons, it was necessary to take an average length, and to mark that on a metallic rod or plate, carefully preserved for public use.

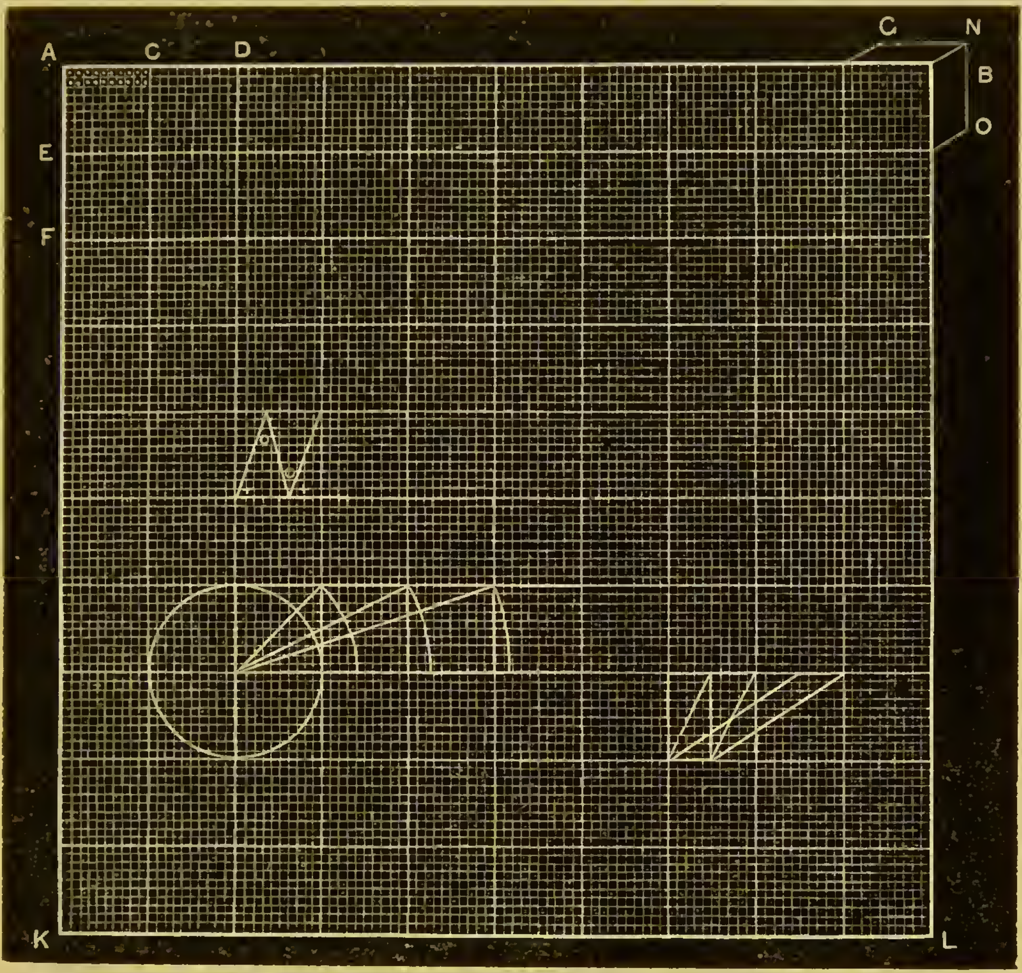
1359. Then in regard to *number*, the human body has on the hands *ten* fingers, offering a fixed standard with which all other numbers can be compared. After counting up to ten, and giving to each amount a distinct name, viz., one, two, three, &c., men did not require to make many more such distinct names, but merely joined two or more of the ten first chosen, to signify others, naturally shortening somewhat the compound words for the sake of easier utterance. Thus, in the English language, three and ten are contracted into *thirteen;* four and ten into *fourteen;* five and ten into *fifteen*, and so forth. Two tens similarly become *twenty;* three tens *thirty;* four tens *forty*, and so on. For the sake of clearer distinction, however, as the groups become much larger, instead of the word tenty for ten times ten, after the word ninety for nine times, they use *hundred*, and then treat that as a larger unit; saying, one hundred, two hundred, three hundred, &c., and for still larger numbers (still merely tens multiplied), they use the words thousand, million, billion, trillion, &c., which procedure may be carried to any extent. By such means a shipload of peas might be counted, and the sum be named without the error of a single pea.

1360. Besides having clear standards, as above described, of *size* and *number*, it is important that all persons should have familiar acquaintance with a few common *shapes* of things, with which, to aid conception and description, the infinite variety of shapes occurring in nature may be at once compared. Such are—1. The *straight line.* 2. The exactly *plane* or flat surface. 3. A square *plane divided* into smaller squares, as on a chess-board, or a common multiplication table. 4. The *circle* and its simple divisions. 5. Some figures such as *squares* and *triangles,* formed by straight lines drawn on a plane. 6. The *globe* or ball with fixed points and lines upon it. 7. The *vertical line* of a plummet, and the *level line* crossing that. (Greater detail is given from page 708 to page 711.)

The members of any civilized community acquire unavoidably, during their intercourse with one another, a considerable amount of the knowledge referred to, which may be called the mathematical knowledge of common experience, although from not having made a formal study of the subjects at school, many may not be aware that they are in any degree mathematicians. Thus, everybody knows that a square has four equal sides, joined at four square corners; that a circle has every point of its circumference at the same distance from its centre. And a person would be deemed of dull apprehension who could not discover when a tree, or flagstaff, or a pillar, did not stand nearly upright; or when a floor was not level. Much of the work of the mason and carpenter is guided by mathematical rules; and, with advancing civilization, new trades and occupations among the labouring classes are every day springing up, as among railways, steam-ships, docks, &c., which demand like scientific knowledge.

As, in dealing with all the matters above referred to, the process of numbering or computing is fundamental and a chief part of what has to be done, it is befitting here to describe with some detail the remarkable progress which has been gradually made in the art of numbering or computing.

1361. The adjoining square plane surface is minutely subdivided by parallel lines drawn directly across it, at equal distances, from side to side, and from top to bottom, into similar small squares ranged in straight lines. It manifests very distinctly to the eye of the observer, how the process of counting by tens produces the important results obtained. The first ten small squares with dots in them, from the corner A, towards the opposite corner C, mark or recall the ten fingers used as the root of all that follows. This number ten is called the first power of that standard number of units. The row reaches to the stronger line drawn from C downwards. The second row of ten, placed also between the lines descending from A and C, lies immediately below the first, making two tens, or twenty small squares, occupied, if desired, each by a single pea. The third row of ten still farther down, makes three tens or thirty squares; and the person counting may proceed in the same way to the tenth row, which makes ten times ten, or completes a hundred, called the second power of ten, and also its square, because the ten rows close together form a square. If the counting then goes on similarly, towards the right hand B, a second square is formed between the lines C and D, making two hundreds, and then a third square appears, and so on until the broad line of squares is formed from A to near B, making ten times a hundred or one thousand, which is called the third power of ten; it is called also the cube, because if little cubes,



like common dice, are placed in the small squares, the whole ten hundreds, when laid one upon another in succession would form a cube (sometimes called a solid square), containing one thousand dice. If, however, instead of piling one square upon another, the counting is continued all in flat extension, a second broad line of squares, containing a second thousand, would be formed below the first, and the operation being continued, a third, fourth, and others such would be formed until ten thousand were there spread out. Thus, the fourth power of ten would be exhibited, every unit being visible to the eye at the same time, as shown on the page, and the arrangement would cover a square surface, of which the side line would contain a hundred small squares.

If ten thousand soldiers were confusedly scattered over a plain, a spectator conjecturing as to the number, might approximate to the truth, but if they were quickly formed into ten regiments of a thousand each, and each regiment into ten companies of a hundred each, and each company into ten smaller equal portions, the whole arrangement would be as intelligible as is that of the small squares on the preceding page.

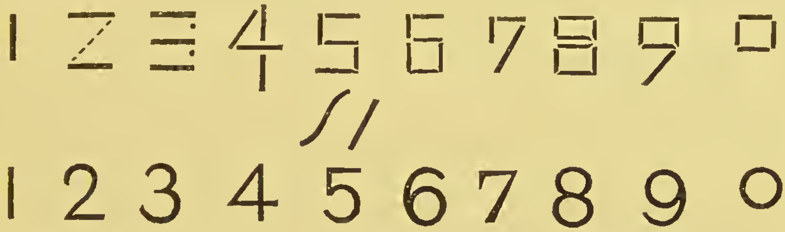
Familiarity with the crossed square above shown, gives to the student a clear perception of important relations among orders of numbers, and among amounts of number as treated of in arithmetic, and among extents of surface and bulk, as treated of in geometry.

1362. This square figure, however, still left a great desideratum to be supplied, to facilitate the operations of counting and computing, namely, a system of significant marks to be used in writing. It was a very simple or obvious expedient in buying and selling to make a stroke, with chalk or with ink, on any flat surface, for every bushel of corn, or measure of liquid, which had to appear in the account rendered, and accordingly it was common thus to make such strokes, one for each measure, and when four had been made, a fifth crossing them would mark five, and two fives would indicate the standard number ten—and such marks might be repeated to any extent. Another ancient scheme of marking was, instead of making lines, to cut notches on the edge of a stick.

1363. The Romans used letters of their alphabet to signify numbers. Single strokes stood for units, the letter V for five, X for ten, C for a hundred, M for a thousand, and so forth, as is still to be seen on the title-pages of books, to mark the year of publication. For instance, MDCCCLXV signifies 1865. But evidently computation made with such marks was laborious and tedious. A truly admirable system had long been devised, but was not known in Europe. It is now in common use over the civilized world. The marks used were for a considerable time called in Europe the Arabic ciphers, because they came hither through commerce with the Arabs, but they were eventually ascertained to have come from farther East, probably from Hindustan.

These Indian ciphers, until explained, might appear only chance forms, like some of the alphabets of sound recently proposed, but they really constitute one of the most ingenious devices of the human intellect, without which many of the arts of modern civilization, such as the use of logarithms in astronomical and other calculations, would not yet have existed.

1364. They seem to have originated as follows:—ten similar short pieces of wood being prepared, one of these laid down on



a table, as shown in the engraving, marks or signifies the number *one*. Two of them laid horizontally, as shown, mark two; three such mark three; four placed, as in the peculiar position here shown, mark four; five of them with ends joined, as shown, mark five, and so on to the end. These characters, when formed quickly with pen or pencil on paper, take the rounded form shown in the second line, as they are now commonly written. It is to be remarked that the figure 5, if written very quickly or in running hand, would become more and more nearly as it is shown here between the lines, like the waved Italic letter S, or even would be only a slanting straight line, beginning high on the right hand, and ending low on the left. So the cipher for 7, taking the long slanting line to signify 5, with two strokes added means 7, and the cipher 9 appears as the slanting line 5, added to the four short lines, meaning 4, converted into a circle. The last cipher 0, originally made by four lines, has no signification when standing by itself, but when added to, or intermixed with other ciphers, changes very much their import, as now to be explained.

The ciphers standing singly mean the sum indicated by the number of short pieces of wood, or elementary strokes, united to form them, as shown in the upper line, but if two or more ciphers are placed together as in the written expression for the current year, 1865, while the cipher on the extreme right indicates units, and therefore five, the one next to it towards the left, means tens (here six tens or 60), the third means hundreds (here 800), and the fourth on the left means thousands (here 1000), and the whole expression is read, One thousand eight hundred and sixty-five.

1365. Nothing can exceed the simplicity with which the arithmetical operations of *addition*, *subtraction*, *multiplication*, and *division* are performed with the aid of these ciphers. To advance however in this direction would be to write a treatise on arithmetic, which is not the purpose of the book. The following simple cases will recall the meaning of the terms:—

ADDITION OF FIFTY.

The present year being	1865
In fifty years	50
The current year will be	1915

SUBTRACTION OF A HUNDRED AND SEVENTY-SEVEN.

The present year being	1865
A hundred and seventy-seven years ago	177
The year was	1688

MULTIPLICATION BY FOUR.

A ship's crew having two hundred and sixty-two men	262
Four such ships so manned	4
Would contain	1048

DIVISION BY SIX.

A charity of forty-two pounds divided between six poor people	6)42
Gives to each seven pounds	7

1366. Besides the ten precious ciphers described above, which so remarkably abridge the labours of computation, there is what may be called an *arithmetical short-hand*, which still farther abridges such labours. Being valuable and easily learned, all persons who have to calculate should know it, yet few do, from the erroneous notion that it is a difficult algebra. It consists of ten signs which are here exemplified in use.

No.	The Signs.	Their Meaning.	Examples.
1	$+$	Addition	Thus $8 + 4$ signifies 12
2	$-$	Subtraction	„ $8 - 4$ „ 4
3	$\times$	Multiplication	„ 8×4 „ 32
4	$\div$	Division	„ $\frac{8}{4}$ „ 2
5	$=$	Equality	„ $8 + 4 = 12$
6	4^2	Second power, or square of the number marked	„ 4^2 signifies 16
7	4^3	Third power, or cube of the number	„ 4^3 „ 64
8	$\sqrt[2]{\ }$	Square root	„ $\sqrt{16}$ „ 4
9	$\sqrt[3]{\ }$	Cube root	„ $\sqrt[3]{64}$ „ 4
10	: : : :	Proportion*	„ 3 : 4 : : 12 : 16

* Proportion is thus expressed in words and in ciphers:—

As the number three is to four so is the number twelve to sixteen.

Or, as 3 : 4 : : 12 : 16.

This form is familiarly known as being that of the *Rule of Three*, called, from its extensive utility, "the Golden Rule." If any numbers are taken, as here 3 and 4, whatever relation (as part or multiple) the first has to the second, the same relation the third has to the fourth; and if any three are given and placed in the order here shown, the fourth proportional can be found by multiplying the second and third together, and dividing the product by the first.

Every schoolboy knows the *Rule*, and readily applies it, but often without perceiving why it must give true answers. Students, by joining the idea of some objects to that of the abstract numbers, often obtain a clearer conception, thus:—As 3 shillings are to 4 shillings so are a dozen times 3 shillings (namely, 36) to a dozen times 4 (namely, 48), and so must be the third part of 36 (viz., 12) to the third part of 48 (viz., 16). The ciphering stands thus:—

3 : 4 : : 12 : 16
4

3) 48 (16

The case can be clearly stated also in the form of a fraction, as $\frac{3}{4}$. The relation of one number to another is clearly seen by supposing an object or quantity

1367. That persons generally, in a civilized community, unavoidably acquire a certain amount of knowledge of the mathematical subjects enumerated in Art. 1360, and that they believe other people to possess nearly the same knowledge is proved by the manner in which persons remark upon or describe a new or strange object presented to them. They will say, for instance :—

No. 1. Of a line—that it is or is not—quite straight.
,, 2. ,, plane ,, quite flat.
,, 3. ,, chess-board ,, uniformly divided.
,, 4. ,, circle ,, truly round.
,, 5. ,, square ,, with equal sides and square corners.
,, 6. ,, globular object ,, a perfect ball.
,, 7. ,, tree or pillar ,, quite upright.

And they would not use such terms if they did not believe the listeners able to understand them.

These objects, more fully described, are

No. 1, the *straight line.* It is seen in a thread, by which a weight is suspended, as in the string of a plummet, or in the edge of a flat solid ruler, called a straight-edge, which ruler is formed to coincide with such string. It is seen also, nearly perfect, in any stretched cord, as the string of a musical instrument, or the line used by masons in building straight walls, and by gardeners in forming borders of flower-beds. Light moves in straight lines, and enables persons by the eye to place objects in straight rows.

No. 2, a *perfectly plane,* or flat *surface,* is that which, when a straight line or edge is applied to it in any direction, so as to touch it at any two points, it similarly touches it at all points, between these two. It is seen perfect in the surfaces or faces of natural crystals, and nearly perfect in the surface of tranquil water, or of ice formed upon that, and in plane mirrors. Two polished surfaces of plate-glass applied closely to each other, sometimes cohere so strongly as not to be separable without fracture, proving the general contact.

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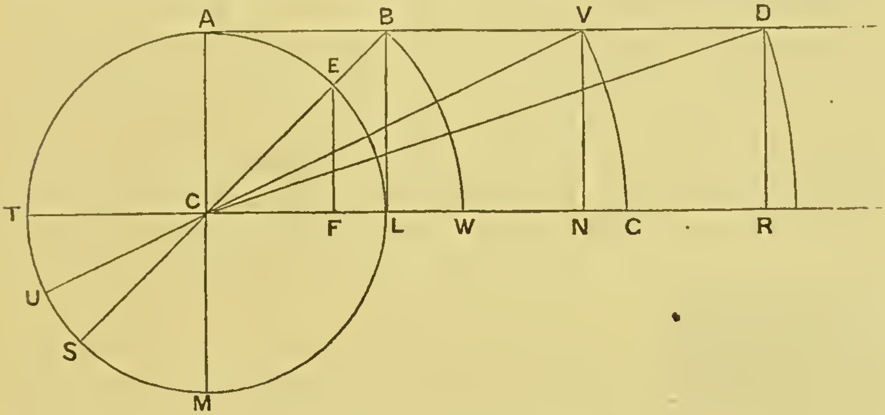
to be divided into a certain number of parts (as here into four), of which a portion (here three) are taken, and the act is thus expressed, $\frac{3}{4}$. By then multiplying the third new number 12 by 4, to show how many fourths are in the 12 wholes (viz., 48), and by dividing that product by 3, to show how often 3 fourths are found in 48 fourths (viz., 16 times) the answer is obtained.

It is evident that any fraction, as $\frac{3}{4}$, of which the terms are either both multiplied or both divided by the same number, remains of the same value, as $\frac{2}{4}$ thus multiplied by 6 gives $\frac{12}{24}$, and that divided by 3 gives $\frac{4}{8}$, which divided by 4 gives ^{1}.

No. 3, two straight lines may be drawn on a plane surface, to cross each other in such manner, as to form, where they meet, four equal square corners, or angles, called right angles. Other lines may then be drawn on the plane, parallel to these, at equal distances, so as to divide the whole surface into a multitude of small equal squares (see page 703), like those of a chess-board, or of the common multiplication table. This large crossed square can then serve as an accurate measure for many purposes. One purpose is to aid the processes of numbering, as already described.

No. 4, a *circle*, is a curved line, A L M T, drawn round a central point C, on a plane surface, from which centre every part



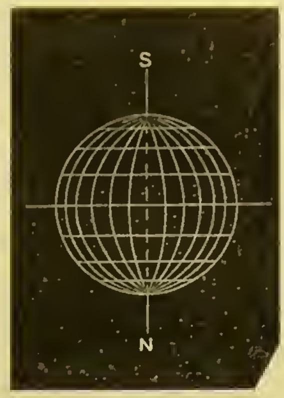
of the curve is at exactly the same distance. The bent line is called the circumference. A straight line drawn from any point of the circumference, as A, through the centre (C) to the opposite side of the figure M, is called a *diameter*. The half of such line, as from A to C, or L to C, is called a *radius* (the Latin word for a spoke; because it resembles the spoke of a wheel). The circumference for any purpose may be divided into any number of equal parts. Thus, the dial or face of a clock, has on it twelve divisions for the hours, and sixty for the minutes. For general purposes it is usual to divide circles into three hundred and sixty parts called degrees (thus written 360°).

If two lines are drawn from any points in the circumference of a circle, as E and L, simply to meet or to cross each other at its centre C, they form, where they meet, a corner, called an angle, which is large or small, according to the portion of the circumference lying between the points, which portion of the circle is then said to subtend or measure the angle. If the whole circle be divided into 360°, the quarter circle A L has 90°, forming what is called a right angle, or square corner, and the half of that, or the angle E C L, has 45°, a magnitude often named as indicating the line C E, half way between the direct upright, or vertical line, C A, and the level or horizontal line, C L.

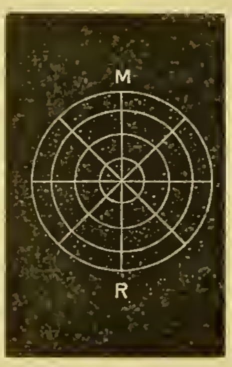
It is evident that the sum of all the angles which can be formed at the same point, on one side of a straight line, as T C L, must be two right angles, or equal to two right angles. An angle larger than a right angle, as T C E, is called a blunt or obtuse angle; one smaller than a right angle, as A C E, or E C L, is called a sharp or acute angle. The line A B, at right angles to the radius C A, and just touching the circle at A, is called the tangent, or touching line, to the circle at A, for the angle of 45°, A C B; and the line C B, cutting the circle at E, to reach the tangent at B, is called the *secant* (secare, *to cut*) of the angle A C B. The longer lines A V and A D are the tangents of the larger angles A C V and A C D, and the lines C V and C D, are the corresponding secants. The line E F, drawn from the cutting point E, perpendicular to the radius C L, is called the *sine* of the angle E C L, as B L is the sine of the same angle in a circle of larger radius C B, or C W.

No. 5, *lines about a circle.* By drawing a circle on the crossed square, from the meeting of any two lines as its centre, portions of the crossing lines instantly become the radius, sine and tangent, of any angles formed by oblique lines drawn to the centre; and the relations of these lines to one another, and to the size of the angle concerned, are at once evident, and can be measured, as is shown by the figures indicated in stronger lines on the crossed square. The various above-named lines about a circle have the same relations or proportions among themselves whatever the size of the circle be, so that any one and its name, for a given circle, being known, all are known.

No. 6, the *globe* or *sphere*, is a solid form, such that every point on its surface is at the same distance from its centre. It is seen nearly perfect in a truly-turned billiard-ball, in soap-bubbles, in many fruits, and in grains of sportsmen's shot-lead, which, in the molten or fluid condition, is rained down in drops from a height, and becomes solid by cooling as it descends. This earth and all the heavenly bodies approach in form to the sphere, obeying the law of universal mutual attraction, of the constituent parts. They deviate from the perfect sphere only because of the centrifugal force of the substance in rotation near their equator. The hills, and hollows, and sea-bottoms, on the surface of the earth are very inconsiderable deviations in proportion to its vast size.

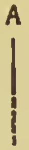


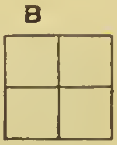
The adjoining figure represents a globe outlined by circles of wire, as bird-cages are. These circles, all meeting and crossing at two opposite points, called the poles, cause the spaces between them to widen gradually from the poles towards the middle circle between the poles, called the equator. These circles on the earth are called meridians or circles of longitude, and the circles crossing them, and keeping them at fixed distances, are called circles of latitude. By numbering the two sets of circles, and dividing them into equal parts, every spot on earth has its distinguishing longitude and latitude. The reason is here apparent, of why the degrees of latitude are shorter as they are nearer to the poles, and why the shortest way between places directly east or west of one another, in high northern or southern latitudes, is not in lines of latitude, which are parts of small circles, but in parts of a great circle of the globe. This second figure shows the earth as it would be seen by a spectator far from it, looking directly in the line of the axis, towards one of the poles.

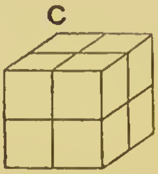


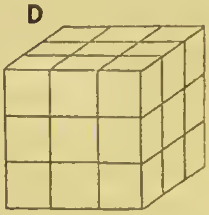
No. 7, the *plummet*, is a ball of lead suspended by a thread, of which the direction points always towards the centre of the earth, as explained in Art. 156. It is a device of the highest utility to men for innumerable purposes. The mason can scarcely place a stone aright in a building without its aid. It tells everywhere the direction of a level line, that being always directly across the vertical. A single observation, made with the aid of a plummet, of the sun's apparent height at noon, tells the latitude of the place. In ships on the moving waves, the plummet cannot, of course, be used, but the nearly level sea-horizon can then serve in its stead.

There are a few truths connected with the matters treated of in the last four pages, which are far from being self-evident, and respecting which the student should be early informed.





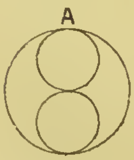


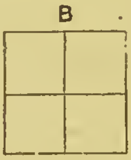


1368. (*a*) *The relations between lines, surfaces, and solid bulks.*—If the length of a line, as the upper dark half of the line A ($\frac{1}{4}$ of an inch), be doubled or tripled, the line is just twice or three times as long, as indicated by the dotted part added to the dark line A.

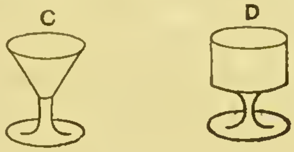
But if the side of a square surface be doubled, the square area becomes not twice, but four times as great, as seen in fig. B. If the line be tripled, it has not three times the area, but nine times, as shown in the near face of the solid, D.

If the side of a cube be doubled, as shown at C, the bulk of the solid is not doubled, but made eight times as great. If the side be tripled, the bulk is made not three times, but twenty-seven times as great, as may be counted in figure D, or as is proved by putting common dice together, to complete a solid mass.—Thus, the simple line multiplied increases as:—1, 2, 3, 4, 5, &c.; the area or surface increases as—1, 4, 9, 16, 25, called the squares; the solid bulk or cube increases as—8, 27, 64, 125. The explanation of solid increase is instanced here by supposing the shape to be cubical, as of dice heaped, but the same proportion is maintained between like solids of any shape. Thus if the moon had just one fourth of the diameter of the earth, it would be a sixty-fourth part as large. The planet Jupiter has only ten times the diameter of the earth, but has a thousand times greater bulk. The Great Eastern steamship is only about three times as long, and broad, and deep, as some of the huge ships of war, but can carry twenty-seven times as great a load, or has about twenty-seven times the capacity.

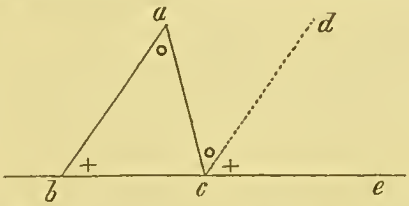




1369. An amusing instance of error fallen into with regard to the relations of dimensions here considered, occurred some time ago, when a company supplying a city with water, had bargained to pay 200*l.* a year to the proprietors of a mill-stream, for the quantity of water which could pass through a pipe of nine inches diameter, under a given pressure. After a time the company wanted more water, and they agreed to double the payment for a second pipe of the same size. The first pipe appearing decayed, permission was asked to have, instead of the two pipes, one pipe of double diameter. This request being granted, four times as much water was obtained for only double the price. There are peculiar relations between the capacity of forms that are unlike each other. For instance, the conical wine-glass, shown here, holds only one third part as much as the cylindrical glass beside it, and a ball which can just fit a certain cylinder has exactly two-thirds of the bulk of the cylinder.



1370. (*b*) *In all triangles, whatever their shape, the sum of the three angles is just equal to two right angles or square corners* (page 658). So, if any two of the angles are known, the third also becomes known. The proof is as follows:—Let *a b c* be any triangle, of which the side *b c* is prolonged to *e*. The two angles on the two sides of the line *a*, *c*, must be either two right angles, or equal to two right angles. If the line *d c* (here dotted) is drawn parallel to *a b*, it makes three angles at *c*, still equal to two right angles. Now these three angles must always be exact counterparts of the three angles of the triangle; for the angle *a c b* is actually one of both sets, and then the angle *a b c* (marked here by a small cross) will always be equal to the angle *d c e* (also marked by a small cross), because on the corresponding side of the line *d c*, parallel to *a b*; and the angle *a* must be always equal to the angle *a c d*, because they are on alternate sides of the line *a c* between parallels.

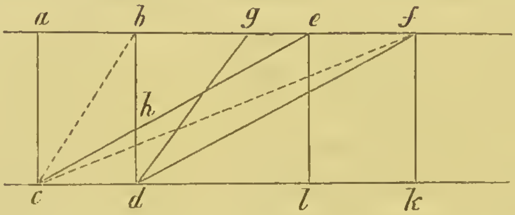


1371. (*c*) A triangle consists of three sides, and three angles, and if three of these six particulars are known, one of the three being a side, all the others are found by easy calculations. Thus the moon may be considered to be at the distant angle of a triangle, having for its base the known distance of the observatories of Greenwich and the Cape of Good Hope, and for its other sides having rays of light from the moon to the observatories. The angles formed between these rays, and the base line of distance can be measured, and, with the known length of the base, complete the three things necessary to be known to discover the length of the sides or the distance towards the moon.

That distance is found by computation, as described at Art. 1270. The third angle of the triangle is that at the moon, and is called the angle of parallax, explained at Art. 1272.

It is evident that the distance of any unapproached object, as a rock in the sea, visible from the land, or a flagstaff on a distant hill-top, can be found in this way, and roughly measured on a drawing made on a crossed plane (page 703); and what can be roughly so drawn can be exactly computed. It is clear that in any case, if a distance of known length be used as the base line of a triangle, and the angles formed at the two extremities of that base are known, the lines making these angles with the base, if prolonged, can meet only in one point, the position and length of which can therefore be exhibited on a drawing.

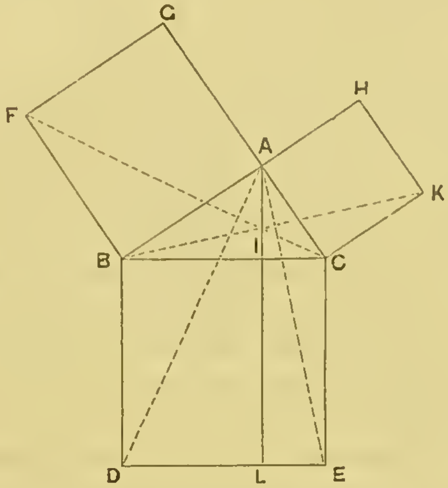
1372. (*d*) If between any two parallel lines, as *a f*, and *c k*, any parallelograms are formed, as *a b d c* and *e f d*, *c* on the same or equal bases, they are perfectly equal in size or



area, however much they differ in obliquity, as in *b g c d*, or *e f d c*. A simple illustration and proof of this is offered by heaping up playing cards in a mass, to fill and occupy with their ends the space *a b c d*. By then placing a straight board in the slanting position, *g d*, and pressing the cards towards the board to lean against it, the same ends will occupy with their edges the oblique space *b g c d*, with exactly the same amount of surface exposed towards the spectator, as when resting directly over one another in the space *a b c d*. The same would still remain true, if the inclined board occupied the position *f d*, and the oblique parallelogram were therefore *e c d f*. Then the parallelograms being equal, their halves, namely, the triangles, *b c d* and *f c d*, would also be equal.

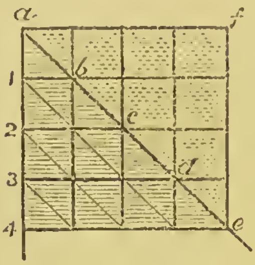
1373. The fact thus described furnishes the proof of the famous forty-seventh proposition of the first book of Euclid's Elements, said to have been discovered by Pythagoras, and in thankfulness for the discovery of which, he is said to have caused a hecatomb (a hundred oxen) to be sacrificed to the gods.

The truth proved in that demonstration is, that if, on any triangle, as A B C, having in it a right angle, as A, squares are drawn on the three sides, as here shown, the square on the largest side, B C, is exactly equal to the two squares on the smaller sides, B A and A C.



The proof is obtained by drawing, first, the line A L from the right angle to L in the base of the greatest square, parallel to the sides C E and B D, and then the four oblique dotted lines, which complete two pairs of equal triangles. Then as F B and G C are two lines parallel to each other, being, in part, sides of the same square, G F B A, the triangle F B C is equal to half the square or parallelogram G F B A resting on the same base, and between the same parallels; and, again, the triangle A B D, lying between the parallels B D and A L, is half of the parallelogram B I L D, which is one division of the large square B C D E. Now the two triangles named are equal to one another, for both consist of a side of the large square and a side of the smaller, and have the same-sized obtuse angle between them, made up of a square angle, and the angle A B C. Thus, the halves of the square G A B F and of the parallelogram B I L D being equal, the whole square is equal to the whole parallelogram—part of the large square B C D E. In exactly the same way, the small square A H K C is proved to be equal to the remaining portion or division I C E L of the large square, and, therefore, the two smaller squares formed on the small sides of the right-angled triangle are, in all cases, equal to the one large square formed on the long side, which was the thing to be proved.

If this explanation be comprehended by the young reader, there will be the satisfaction of thinking that what was once deemed a mathematical difficulty has been overcome.



1374. This figure, used also at page 63, to explain the laws of falling bodies, serves well to show some relations of arithmetic to geometry. It is a picture to the eye of the phenomenon, exhibiting the relation at every instant, between, first, the time of the fall; second, the velocity acquired; and third, the amount of fall. The perpendicular line *a* 4 represents the time of fall, and it may be divided into any number of parts or instants: the first division here *a* 1 represents one second of time. The horizontal lines across, from the line *a* 4 to the oblique line *a e*, represent the velocity uniformly increasing every instant: at the end of the first second it has already attained the rate of 32 feet per second. The amount of triangular space or area between the lines *a* 4 and *a e*, and any one of the horizontal lines, is the measure of the amount of fall, or of the course passed through, up to the instant of time corresponding to that velocity: the area of the first small triangle here, *a* 1 *b*, belonging to the first second of time, indicates 16 feet of fall at the end of the first second. If the question be put, What is the velocity and what the journey performed at the instant marked 3 on the line of time? one has only to observe that the time is three seconds, the velocity 96 feet per second, and the space passed through nine times sixteen, or 144 feet.

1375. *Algebraical Formulæ* is the name given to the precise technical expressions for the relations of quantity among the objects and phenomena of nature, formed by the signs described at page 709, under the head of *Arithmetical Shorthand*. It would be to depart from the plan of simplicity adopted in this work, to enter fully into the explanation of these; but a student who has forgotten his school-lessons of vulgar fractions will do wisely to review them with the aid of a teacher. The laws of force and motion, stated in this work in common language, can be very readily translated into the formulæ.

A treatise on Arithmetic adapted to the purpose of giving command over the formulæ might be very short. If a desire be expressed to have such an abridgment, the author will publish one separately, as a key to certain questions in Natural Philosophy.

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THE END.

LONDON: PRINTED BY W. CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

KING'S COLLEGE LONDON

ELEMENTS

OF

PHYSICS,

OR

NATURAL PHILOSOPHY.

Written for General Use,

IN NON-TECHNICAL LANGUAGE.

By NEIL ARNOTT, M.D., F.R.S.,
OF THE ROYAL COLLEGE OF PHYSICIANS; PHYSICIAN EXTRAORDINARY TO THE QUEEN; MEMBER OF THE SENATE OF THE UNIVERSITY OF LONDON;
ETC. ETC.

SIXTH AND COMPLETED EDITION.

LONDON: LONGMANS, GREEN, & Co.
1865.

Friday

BOUND BY
WESTLEYS
& Co
LONDON